Constructing the Self in Adolescence

Learning What We Like and What We're Like

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Signed Declaration

I, Madeleine E. Moses-Payne, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Impact Statement

This thesis examines self-concept development and autonomy in adolescence. I present a number of studies investigating the cognitive and behavioural processes that adolescents use to reflect on, gather, refine and explore information about themselves. Further, I investigate the associations between these processes and adolescent autonomy and independence. I also present a number of findings exploring how mental health symptoms are associated with adolescent self-concept and the processes used to construct it.

Within academia, this research contributes to the existing literature on self-concept development during adolescence. By investigating the age-related improvements in metacognition and decision making, as well as the formation of self-judgements and preferences, this thesis expands our understanding of the cognitive processes involved in constructing a self-concept. The beliefs we hold about our self-concept have far-reaching impacts on the way we behave, our motivations and our wellbeing, so this work could provide important avenues for intervention, influencing both social policy and mental health care.

In terms of dissemination, the work presented in this thesis has resulted in two publications to date (as well as one currently under review) and has been presented at multiple conferences and workshops around the United Kingdom, Europe and the United States. I have developed and extended multiple experimental paradigms to assess self-concept development, which are freely available to use by other researchers. The insights gathered through this have the potential to inform future studies and theories related to adolescent development.

Outside of academia, the work presented here could be built upon to generate various guidelines to promote adolescent wellbeing. By identifying the factors that contribute to the formation of self-concept during adolescence, interventions can be developed to support young people in developing a positive self-concept and promoting mental health. For example, the investigation of the impact of exploration on affect and social network growth provides valuable insights to better support young people at the transition to a new school. With further investigations on adolescent self-concept and independence, educators, counsellors, and parents could utilize these findings to design interventions and strategies that enhance adolescents' decision-making skills, self-judgement, and self-esteem. This could have a direct impact on adolescents' well-being, leading to improved mental health outcomes and increased resilience during this critical period of development.

Abstract

Self-concept refers to beliefs about our own abilities, traits, and preferences, and how we perceive ourselves in relation to others. The quality and valence of these beliefs can have significant impacts on mental health. In this thesis, I investigate the motivations and cognitive abilities that underlie the formation of self-referential beliefs during adolescence. Adolescence is a critical period for self-concept construction as adolescents gain independence and navigate new environments. In the first experiment, I demonstrate that the ability to reflect upon our own decisions shows age-related improvement during early adolescence. I present evidence that the development of this metacognition may encourage independent decision making during adolescence. I then investigate how adolescents form judgements of their own traits, finding that preferential memory for self-judged versus other-judged traits is heightened in early adolescence and declines across the teenage years and into adulthood. I also demonstrate that negative self-judgements show a quadratic association with age, peaking around age 19, and that preferential memory for positive over negative traits increases across adolescence. In the third experiment, I examine how adolescents can use the process of choosing itself to gain certainty over their own preferences. I show that the use of choice for value refinement increases across early adolescence and is associated with depressive symptoms. In the final experiment, I utilise geolocation tracking and ecological momentary assessment to explore the impact of independent decision making and exploration on affect and social network growth. I also explore how adolescents form judgements of and adjust their behaviour to changing social norms, a potentially important source of information for adolescent self-concept development. I argue that by understanding the factors that contribute to the formation of the self-concept during this critical developmental period, we can better support young people in developing a positive self-concept and promoting mental health.

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SRE	Self-reference effect
CIPC	Choice-induced preference change
SART	Sustained attention to response task
SoA	Spreading of alternatives
FCP	Free-choice paradigm
RPR	Ratings, preference choices, ratings
RcRP	Ratings, colour choices, ratings, preference choices

Chapter 1

Introduction

Adolescence is a critical developmental period during which we construct our sense of who we are and forge our own path to independent adulthood. Adolescence is a time of remarkable opportunity, for adolescents themselves and researchers alike. During adolescence, individuals explore their sense of self, develop interests and meaningful goals and learn decision-making skills that will shape their adult lives. At the same time, understanding the mechanisms driving adolescent development provides researchers with a unique opportunity to promote positive self-concept development and mental health.

Defining adolescence

The term "adolescence" originates from the Latin word *adolescere* meaning "to grow up or to grow into maturity". The first use of the word "adolescence" occurred in the 15th century but the "discovery" of adolescence as a key developmental phase is often credited to G. Stanley Hall (Lerner & Steinberg, 2004). In his 1904 paper "Adolescence", Hall proposed that adolescence was a modern developmental stage due to changing Child Labour laws that gave young people new freedoms and fewer responsibilities (Hall, 1904). However, long before the outlawing of child labour, Ancient Greek teenagers appear to have behaved in ways not too dissimilar from the typical behaviours observed in adolescents today. Socrates stereotyped young people in a quote that could be mistaken for a modern-day depiction, he described their "contempt for authority", continuing that they "disrespect their elders and love chatter in the place of exercise" (Patty & Johnson, 1953). Aristotle described adolescents as "passionate, irascible and apt to be carried away by their impulses […] the age when people are most devoted to their friends" (Aristotle, 350 BC). Later, Shakespeare portrayed a shepherd in The Winter's Tale, wishing "I would there no age between ten and three-and-twenty, or that youth would sleep out the rest, because there is nothing in the between but getting wenches with child, wronging the ancientry, stealing, fighting" (Shakespeare, The Winter's Tale III. III. 59).

These stereotypes of adolescents have survived for centuries, tending towards negative depictions potentially because of a "kids these days" effect – the well-documented tendency of adults to perceive the next generation of youth to be lacking in various ways compared to their own (Protzko & Schooler, 2019). These pervasive stereotypes may tell us about some of the features of adolescence that are culture-invariant. Adolescence is the time of life during which young people develop their independence, through constructing a sense of who they are and where they belong within social groups (Sebastian et al., 2008b). This strive for individuation and autonomy, separation from family, and social reorientation towards peers (S.-J. Blakemore, 2008; Koepke & Denissen, 2012a) may be accompanied by certain behavioural tendencies, such as increased risk taking (Ciranka & van den Bos, 2021; Leather, 2009), exploration and novelty seeking (Saragosa-Harris et al., 2022), resistance to authority (as described by the Ancient Greek philosophers; Van Petegem et al., 2015) and a heightened sensitivity to peer feedback and need for social belonging (Tomova et al., 2021).

In order to establish appropriate legal and social frameworks, alternative contemporary definitions of adolescence have necessitated the use of age ranges to capture the biological, psychological and social changes that occur during this period. The proposed ages vary, ranging from 10–24 years (Sawyer et al., 2018a), 10–19 years (World Health Organisation), and 15–24 years (United Nations). Others have argued that it would be inaccurate to equate the brains of a 13-year-olds with those of a 19-year-olds and have instead suggested that adolescence should be divided into distinct developmental stages of early, middle and late adolescence and young adulthood (Casey et al., 2020). These conflicting definitions likely reflect the diverse motivations underlying the conceptualization of adolescence and the divergent foundations of evidence upon which they are based. Clearly, the complexity and multidimensionality of adolescence make it challenging to capture the entirety of this life stage within a single definition.

A widely accepted contemporary definition of adolescence posits that adolescence begins with the onset of puberty and concludes with the ‘assumption of a stable adult role’ (Patton et al., 2016a). This definition effectively encompasses the important task faced by adolescents, which involves achieving independence and constructing a stable self-concept. In this thesis, I investigate some of the processes by which adolescents may achieve independence, and learn about what they like and what they’re like.

Defining self-concept

The self-concept provides answers to the basic questions “Who am I?”, “Where do I belong?” and “How do I fit in?” (Oyserman et al., 2012). Despite being one of the most studied areas of psychology, there is not as yet a single agreed-upon definition of self-concept, and the way it is defined varies across disciplines and research methodologies. Many define the self-concept as an organisational structure or schema, containing knowledge and beliefs about the self and a repository of autobiographical memories (Harter, 2012; Markus & Wurf, 1987). This definition refers to content: the self-concept is made up of information about our traits, opinions, autobiographical narrative, preferences, appearance and any other self-relevant information. This content, and the ideas we hold about an ideal or future self, can shape behaviour, promoting or reducing persistence, creating motivations and buffering emotional responses (Bandura et al., 1999; Stein, 1995). For example, holding a belief that “I am good at maths” may allow me to persist through a problem even if I initially find it difficult. Similarly, my emotional reaction to receiving negative feedback on a piece of writing will be reduced if I hold a strong belief that "I am a good writer" (Bandura, 1982). When researchers define the self-concept in this way, they are usually referring to "working self-concept", which alludes to the part of the self-concept that is relevant or made salient during a particular task or situation (Markus & Kunda, 1986). We can assess self-concept, conceptualised in this way, using subjective judgements and conscious metacognitive evaluations of the self (Northoff, 2011; M. Rosenberg, 2015). Here, the key words are "subjective" and "evaluations", highlighting the fact that individual's judgements of themselves do not always reflect the objective truth about their abilities and that judgements of the self naturally carry some valence.

This conscious evaluation of the self is sometimes termed 'self as subject' (Northoff, 2011), but another line of research conceptualises 'self as object' (Kim & Johnson, 2014; Sui & Gu, 2017). This focusses on how relating information to the self alters information processing, including attention, memory, visual awareness and decision making (Conway & Pleydell-Pearce, 2000; Macrae et al., 2017; Sui et al., 2012a). In general, relating information to the self enhances performance, in that information becomes more memorable, processed more quickly and prioritised in visual awareness. I touch upon this aspect of self-concept in Chapter 4, in which I assess how relating information to the self enhances memory and perceptual decision making.

Otherwise, in this thesis, I mostly rely on conscious self-evaluation to assess the self-concept. I focus on how these beliefs develop over adolescence and shape (and are shaped by) independent decision making, including how adolescents reflect on their decisions, gather information about themselves, use decisions to shape their preferences and how they gain autonomy through this process.

Developing self-concept

Harter (2012) proposed that the self is a construct that is both cognitive and social. The cognitive aspect refers to its dependence on cognitive development, where the advances (and limitations) of a young person's developmental stage determine the complexity of the self-concept and the tools available to them for constructing it. The social aspect refers to how the self-concept is shaped by interactions with parents, peers, teachers and those in the wider sociocultural context, through social feedback and social comparison.

Primitive aspects of the self, which require minimal explicit self-reflection, emerge early in development. Some have argued that new-borns have a primitive self-awareness, based on the demonstration of imitation in neonates (Welsh, 2006) and their ability to discriminate synchronous from asynchronous visual-tactile stimulation to their own body (Filippetti et al., 2013). By around 15–18 months, infants reach an important milestone in self-awareness, as they are able to recognise themselves in the mirror, responding to a mark on their face or head by touching their own body rather than the mirror (Amsterdam, 1972; Rochat & Striano, 2002). These early manifestations of self-awareness lay the foundation for the development of a self-concept. Around 2–3 years, infants start using self-referential pronouns like "I" or referring to themselves by their own name, which contributes to their growing understanding of themselves as separate individuals (Cicchetti & Beeghly, 1990). During childhood, the self-concept continues to expand and solidify. Children start to develop a sense of personal agency and self-efficacy as they acquire new skills and they begin to be able to incorporate feedback from others (Bandura, 1993; Schunk, 1983).

Many researchers have emphasised that adolescence is a key developmental stage for self-concept development (Crone et al., 2022; Sebastian et al., 2008b). Self-concept construction in adolescence may be driven by an increasing independence from caregivers and the need to navigate new and changing social environments (Bos, 2013; Koepke & Denissen, 2012a). There is good evidence that adolescents become increasingly concerned with their self-concept (Sebastian et al., 2008b), especially as compared with others (van der Aar et al., 2018a), and self-consciousness peaks during this developmental period (Somerville et al., 2017). It has been proposed that this may be because self-consciousness and self-conscious emotions, such as embarrassment, shame or pride serve as interpersonal markers, allowing us to reflect on our status within the social group (Leary et al., 1995; Sznycer, 2019).

Development of the self during adolescence was described by Erikson (1963), as part of his "Identity versus Role Confusion" stage of psychosocial development (Erickson, 1963). Erikson's key proposals about adolescent self-concept development were based around a feeling of confusion or insecurity about the self during adolescence, which is remedied by experimentation and exploration of different versions of the self. Erikson suggested that forming a stable sense of self was essential for wellbeing and success in adulthood. Influenced by Erikson's (1963) work, Marcia (1966) described two dimensions of adolescent identity formation: exploration, i.e. actively questioning and weighing various identity alternatives before deciding which values, beliefs and goals to pursue; and commitment, i.e. making identity choices and engaging in activities to implement them (Marcia, 1966).

Erikson and Marcia provided interesting grounds for the study of adolescent self-concept development, but the cognitive processes of exploration and identity formation through commitment were not clearly defined in cognitive terms. In this thesis, I aim to investigate some of the cognitive and behavioural processes that adolescents might use to explore, refine and gather information about themselves. Indeed, a number of cognitive processes undergo significant maturation during adolescence and may drive self-concept development.

Cognitive processes driving adolescent self-concept development

Metacognition

Metacognition refers to "thinking about thinking" (Flavell, 1979), and is often separated into monitoring and control (Koriat & Goldsmith, 1996; Nelson, 1996). Metacognitive monitoring refers to subjective appraisals of our cognition, and an individual is considered to have effective metacognitive monitoring if their subjective appraisals closely track their objective performance (in situations where performance can be objectively measured; Fleming & Lau, 2014). Metacognitive control describes the use of such judgements to adjust one's cognitions or behaviours, for example, setting a reminder after judging that you will be unlikely to remember a specific task (Finley et al., 2010). In this thesis, I focus on monitoring, because of its relevance for self-concept construction and independent decision making.

The ability to accurately reflect on our own behaviours may help us to form more accurate representations of ourselves (Rouault & Fleming, 2020). Furthermore, advanced metacognition allows us to become better decision makers, to better collaborate with others by deciding when to seek further information or help from others, but also when to incorporate versus ignore such information (Frith, 2012; Heyes et al., 2020).

Across childhood, there are significant changes to metacognitive abilities and independent decision making. Preverbal infants have been found to be able to internally monitor the accuracy of their own decisions (Goupil & Kouider, 2016). In one such study, infants persisted in searching their chosen opaque box for a hidden toy for longer if they evaluated their choice as correct (Goupil & Kouider, 2016). Once able to express their internal states, at around four years old, children exhibit some metacognitive knowledge, for example, demonstrating understanding of the factors that might influence memory performance such as list length, time given to study items and the age of the participant (Yussen & Bird, 1979). Young children may possess basic metacognitive monitoring abilities, with some work demonstrating that children as young as three were able to discriminate accurate from inaccurate responses in a perceptual and lexical identification task; this discrimination improved across 3-, 4- and 5-year-olds (Lyons & Ghetti, 2011). As children develop, they become better able to use their metacognitive skills to incorporate information from others (Selmeczy & Ghetti, 2019). For example, when studying 5–9-year-olds, older children show a greater capacity for incorporating probabilistic hints (70% accuracy) about how likely it is that an item is 'old' or 'new' in a memory task. The accuracy of metamemory monitoring (how closely judgements of accuracy match memory performance) was associated with overall accuracy improvements after receiving hints about the correct answer in 9-year-olds but not in 5- and 7-year-olds (Selmeczy & Ghetti, 2019).

Fewer studies have investigated development of metacognition and decision making in young people past late childhood. Butterfield et al., (1988) measured feelings-of-knowing (FOK) judgements for word definitions in 6-, 10- and 18-year-olds and unexpectedly found that 6-year-olds had higher FOK accuracy than the older groups. However, a later study using the same paradigm in 7–10-year-olds failed to replicate this, and instead showed the expected steady improvement in accuracy of FOK judgements across late childhood (Lockl & Schneider, 2002). A more recent study used confidence ratings of old/new judgements for scenes to assess meta-memory monitoring in children between ages 7 to 15 on three measurement occasions in a longitudinal design (Fandakova et al., 2017), reporting continuous development of metamemory judgements over these ages.

However, one methodological factor potentially overlooked in much previous developmental research is the importance of matching objective performance across age. Differences across age in “Type I” performance (of the cognitive task, e.g. memory performance or perceptual decision making) make it difficult to interpret differences in “Type II” (metacognitive e.g. confidence ratings or judgements of learning) performance, owing to the tight link between Type I and II performance: if an individual is worse at a cognitive task, they will likely be less confident in their performance (Fleming & Lau, 2014). Motivated by this concern, Weil et al., (2013) used a Gabor pop-out task (requiring simple perceptual decision making) in combination with a staircase procedure in order to match performance across a group of adolescents (aged 11–17) and adults (aged 19–41). Participants were asked to judge which of two sets of Gabor patches contained a pop-out (a patch with increased contrast between lines). The relative contrast of the pop-out patch could be adjusted to match Type I performance across participants, thus allowing dissociation between the perceptual decision-making performance and metacognitive judgements of performance. Weil et al. (2013) measured two forms of metacognitive performance: bias (overall tendency to rate confidence as high or lower on the scale) and sensitivity (how well confidence is calibrated to objective performance). They demonstrated continued age-related improvement in metacognitive sensitivity in the adolescent group, which appeared to plateau in the adult group. Metacognitive bias showed an age-related increase in the adolescent group and an age-related decrease in the adult group.

Self-appraisals and self-referential memory biases

Closely related to metacognitive judgements of our own performance is self-appraisal. Self-appraisal usually refers to descriptions of our traits (e.g. “I am attractive”, “I am a fast learner”). Usually self-appraisal is measured by asking participants to rate how well positive and negative traits describe them (Pfeifer & Peake, 2012). Some studies also investigate self-appraisals from different perspectives: direct self-evaluations from the participant's own perspective (e.g. "I am smart") or reflected self-evaluations from another's perspective (e.g. "my mum thinks I am smart"; Pfeifer et al., 2009). This allows us to access different aspects of the self-concept, including what is usually described as the 'looking-glass self' (O'Brien, 2010), which refers to the way we think about ourselves from others' perspectives.

Previous evidence has suggested that self-appraisals become less positive during adolescence (van der Aar et al., 2018a; van der Cruijsen et al., 2018a). While children tend to be overly positive about their own traits, positivity about self traits has been shown to dip in mid-adolescence (van der Aar et al., 2018a; van der Cruijsen et al., 2018a). Researchers have offered multiple explanations for this. First, self-appraisals may become more realistic or more accurate, which may be linked to maturation of metacognitive abilities, as described above (e.g. Weil et al., 2013). Second, direct and reflected self-evaluations become more aligned, potentially suggesting that others' perspectives, which may not always be positive, become more integrated during adolescence (Van der Cruijsen et al., 2019). Third, children may make more temporal comparisons (comparing their past to current self), at a time where the skills they consider when making self-judgements (e.g. drawing, running, writing) are rapidly improving (Harter, 2012). During adolescence, young people may instead increasingly draw upon social comparisons to make self-judgements (Crone et al., 2022), making their judgements more mixed and, on average, less positive than children's (Butzer & Kuiper, 2006; Harter, 2012; Pfeifer & Peake, 2012). Finally, the ability to reflect on another's perspective is known to improve during adolescence, potentially driving greater influence of others' beliefs on self-appraisals (Blankenstein et al., 2020; Dumontheil et al., 2010b). Relatedly, it has been proposed that integrating peers' rather than parents' perspectives may lead to more negative self-appraisals (Pfeifer et al., 2009a), because of parents' tendencies to be overly complimentary of their own children. Indeed, social comparison has been shown to have a negative impact on adolescents' self-appraisals, especially during mid-to-late adolescence (van der Aar et al., 2018a).

This increased social comparison and perspective-taking during adolescence may lead to more negative self-evaluation, but it also allows adolescents to form more complex views of themselves (Sebastian et al., 2008b); for example, making self-appraisals that are differentiated across different social contexts. It may also be important for young people to become more aware of their downfalls, in order to form realistic goals. Therefore, these interacting processes enable adolescents to develop and learn about themselves and others.

Another important aspect of self-concept development is the development of a self-reference effect. The notion of 'self as object' (Sui & Gu, 2017), that the self has elaborative and organisational properties that are superior to other concepts, follows that information related to the self will be better remembered than information that is processed in other ways (e.g. relating information to someone else or processing words for meaning). Indeed, the self-reference effect shows that individuals show superior recall and recognition of words following self-reference, i.e. judgement of self-relevance (Rogers et al., 1977a). The self-reference effect has been found to be a robust feature of information processing, and the effect has been replicated across many different studies (Symons & Johnson, 1997a).

In typical studies of the self-reference effect, participants are asked to judge how well various adjectives describe them or another person and are later given a recognition or recall test for these words. However, self-reference effects have even been shown in perceptual matching paradigms, where shapes are arbitrarily associated with the self or another person and then shape-label pairs are presented to the participant (Sui et al., 2012a). In this paradigm, the participant has to quickly decide whether the shape-label (e.g. square-you) pairing is correct. Participants are consistently faster and more accurate when responding to self-associated than other-associated shapes. It has been argued that such effects provide evidence that the self acts as “integrative glue” allowing for fast and accurate processing of information (Sui & Gu, 2017; Sui & Humphreys, 2015a).

The self-reference effect has been demonstrated in children as young as four (Cunningham et al., 2014). In this study, 4–6-year-olds were shown a picture of their own or a same-sex child’s face and an object and were asked to indicate whether or not they or the other child would like the object. They were later given a recognition task for these objects. Objects that were paired with their own image, and that they judged in self-reference, were better remembered than objects judged in reference to the other child. Many other studies have demonstrated the self-reference effect at various other points in childhood (4–6-year-olds: Andrews et al., 2020; 6-, 7-, 10-year-olds: Halpin et al., 1984; 6–11-year-olds: Hutchison et al., 2021; 6–10-year-olds: Maire et al., 2020; 7–11-year-olds: Pullyblank et al., 1985; 7–13-year-olds: Ray et al., 2009; 3–4-year-olds: Ross et al., 2011; 4-, 5- and 10-year-olds: Sui & Zhu, 2005) and some in adolescence (13–18-year-olds: Dégeilh et al., 2015).

Given that the self-reference effect is posited to demonstrate a form of advanced information-gathering, and the importance of self-relevant information gathering during adolescence, it is surprising that there are few investigations into how it changes across adolescence.

Exploration and autonomy

Adolescence is the period of life during which young people gain autonomy from their parents and can begin to make decisions for themselves (Koepke & Denissen, 2012a). Typical adolescent behaviours may reflect this motivation to leave the "nest" and explore the environment (Leather, 2009; Saragosa-Harris et al., 2022). For example, adolescents tend to show heightened risk taking (Ciranka & van den Bos, 2021; Leather, 2009; Steinberg, 2008), which describes a willingness to engage in activities that have uncertain outcomes, novelty-seeking (Kelley et al., 2004), which describes a drive for new and unfamiliar experiences, and sensation-seeking (Steinberg et al., 2018), which describes a drive for intense, varied and complex sensory experiences.

One influential hypothesis for these behavioural tendencies during adolescence is a dual-systems theory. While there have been some variations on this theory, that suggest slightly differing trajectories of development (Casey et al., 2008; Luna & Wright, 2016; Steinberg, 2008; see Shulman et al., 2016 for review), the general proposal is that the developmental divergence between two brain systems, a "socio-emotional" system and a "cognitive control" system, contributes to characteristic behaviours observed in adolescence. The socio-emotional system is thought to mature earlier, while the cognitive control system continues to develop throughout adolescence. Consequently, it is proposed that adolescents experience heightened affinity for exciting, novel and risky activities, especially in social contexts, which they are less able to restrain because of immature cognitive control capacities. The socio-emotional system is typically proposed to encompass the brain's reward system, and therefore is highly responsive to stimuli that are motivationally salient, such as sex, illicit drugs, or alcohol, as well as social approval.

The dual-systems hypothesis has led to a large body of research investigating the mechanisms underlying exploratory behaviours in adolescence. In one influential study, a remarkably consistent pattern of results supporting the dual-systems hypothesis was observed across 11 countries. Sensation seeking (proposed to be implemented by the socio-emotional system) followed an inverted U-shaped trajectory in 7 out of 11 countries, peaking on average at age 19, whereas self-regulation (proposed to be implemented by the cognitive control system) showed an age-related increase across adolescence in 9 out of 11 countries (Steinberg et al., 2018). In perhaps a more direct assessment of the hypothesis, one study demonstrated that both heightened sensation seeking and impulsive decision making were independently associated with greater odds of adolescents (aged 14–16 at baseline) engaging in alcohol and marijuana use and sexual behaviour (Donohew et al., 2000).

A clear limitation to previous studies is their reliance on self-report, which may be heavily influenced by external demands, especially when asking young people to report on illegal behaviours, sometimes amongst peers or teachers in classroom settings; further, when answering questions such as “I would like to try parachute jumping” (an item from Zuckerman’s Sensation Seeking Scale, 1964), it is difficult to distinguish whether a young person is reflecting upon the rewarding outcome of the experience or their experience with exerting cognitive control in such situations or both.

There have also been a number of critiques to the dual systems viewpoint. A major critique argues that the hypothesis is not sufficiently nuanced to capture the diversity of adolescent risk-taking and exploratory behaviours (Pfeifer & Allen, 2012). Indeed, the literature on adolescent risk taking is mixed, with some reviews challenging the initial proposal that adolescence is a peak period for vulnerability to risk taking (Defoe et al., 2015; Willoughby et al., 2014).

More recently, researchers have challenged the very idea that heightened exploratory behaviours in adolescence are due to a still-developing capacity to exert cognitive control (Do et al., 2020). These researchers point to the positive adaptive benefits of adolescent risk taking for learning about the self, others and the world (Crone & Dahl, 2012; Maslowsky et al., 2019; Telzer, 2016). Some risk-taking behaviours are strategic and may require flexible implementation of cognitive control rather than a failure of cognitive control (Do et al., 2020). For example, an adolescent trying a drug for the first time may require greater cognitive control to overcome the habitual response to avoid this risk. Another adolescent who takes risks routinely may require little to no cognitive control to engage in further risk taking. Essentially, depending on the type of risky behaviour, greater, lesser or no cognitive control may be required in order to enact the behaviour.

Considering the unique goals of adolescence may also allow us to better understand quintessential adolescent behaviours. Adolescents may prioritise activities that allow them to learn about themselves, to gain independence, and to gain approval from others in order to build their sense of belonging. Considering this landscape may allow us to reframe these behaviours as adaptive functions (which can sometimes be applied to dangerous scenarios), rather than failures of a developmentally immature system. This could change the way we approach adolescent interventions; rather than, for example, training cognitive control in adolescence we may find more success in directing adolescents tendency for exploration and risk taking towards positive behaviours, such as, participating in movements for social change, auditioning for a play or training in an extreme sport (Duell & Steinberg, 2019). Indeed, adolescents who have a tendency to take risks with dangerous or negative outcomes also appear to take more risks with positive outcomes (Fischer & Smith, 2004).

Overcoming uncertainty and engaging in exploration may create perseverance and “grit” as well as the opportunity to master new skills, which can aide in developing purpose or identity, friendship and positive socio-emotional functioning (Crone & Dahl, 2012). However, fewer studies have directly assessed these associations. In a recent study, adolescents' exploration of their physical environment was measured using geolocation tracking via their mobile phone (Saragosa-Harris et al., 2022). They found that adolescents who explored more reported more risk-taking activities (mostly negative risks were measured) but also reported more positive affect and larger social networks. This points to the potential of exploratory behaviours in promoting wellbeing and encouraging independence through development of social networks.

Social functioning

The question "Where do I belong?" is important and commonly pondered on by adolescents, as they navigate self-concept formation and social integration (Tomova et al., 2021). Adolescence is a period during which social acceptance and belonging is particularly important, and adolescents may be especially sensitive to peer rejection and influenced by the social norms or expectations of their social group (Andrews et al., 2020). In addition to exploring their physical environment and taking risks, adolescents may explore different social groups, hobbies or interests in order to find a sense of belonging that aligns with their evolving self-concept (S.-J. Blakemore & Mills, 2014a). Building independent social networks is thus a key step towards adult independence (Wrzus et al., 2013).

Perspective taking refers to the ability to understand and consider the viewpoints, thoughts, feelings, and intentions of others. This process may be tightly related to metacognition, in that individuals may use similar or, some have argued, the same cognitive processes to reflect on their own and others' behaviours (Carruthers, 2009; U. Frith & Happé, 1999; Goldman, 2006; Schneider, 2008). One popular method to asses perspective taking uses the Director task (Dumontheil et al., 2010b). In this task, participants view a set of shelves with a number of objects arranged on them. A director stands behind the set of shelves. For some of the shelves both the director and the participant can view the object, while for others, only the participant can view the object and the director's view is occluded. The director then instructs the participant to move objects into different configurations. In order to move the correct item, the participant needs to take the perspective of the director. Therefore, the speed and accuracy that the participant moves the instructed objects is taken as a measure of their ability to refer the intention of the director. Children and adolescents typically make more errors than adults on such perspective taking tasks, suggesting that the ability to take someone else's perspective is still maturing during adolescence (Dumontheil et al., 2010b; Symeonidou et al., 2016b).

Adolescents place great weight on belonging and peer feedback. Adolescents are more likely to take risks in the presence of peers: for example, adolescent car accidents (both in the real world and in simulated environments) are more common when there is a passenger in the car, which is not the case for adults (L.-H. Chen et al., 2000; Gardner & Steinberg, 2005). Adolescents have also been shown to be susceptible to shifting their expressed interest in participating in (hypothetical) risky and pro-social (charitable-giving) behaviours towards the peer group average (Chierchia et al., 2020b; Foulkes et al., 2018; Knoll et al., 2017). In this way, adolescents may be particularly sensitive to group dynamics. Interestingly, anti-bullying interventions that have harnessed social network dynamics to target specific individuals to influence the group have shown promise (Paluck et al., 2016). Adolescents are also more susceptible to experiencing self-consciousness and other social emotions, such as shame, pride or embarrassment (Somerville, 2013; Somerville et al., 2013a), and it has been suggested that these emotions act as interpersonal indicators of the individual's social standing (Sznycer, 2019). Taken together, this body of research suggests that adolescents may be particularly attuned to group norms, as well as their own and others' positions in the social network.

Previous work in adults has shown that people can rapidly learn and adapt to social norms within a virtual environment (U. Hertz, 2021). In this study, participants navigated a grid, competing with other virtual players (controlled by the computer) to collect stars. Participants took it in turns with the other virtual players and on each turn participants could either move one place on the grid or they could zap another player, freezing them for three turns. In one block, the virtual players' algorithm was set to "polite", in that they avoided other players and did not zap them. In the other block, the virtual players' algorithm was set to "competitive", in that whenever possible they zapped other players that were closer to the star than them. Participants played both blocks in a counterbalanced order. Through this, Hertz (2021) could assess how well people adapted from polite to competitive norms and from competitive to polite norms. Hertz (2021) showed that there was asymmetric adaptation from polite to competitive norms compared to competitive to polite, suggesting that people learned more from active behaviours (zapping) rather than behavioural omissions (avoidance). Furthermore, it appeared that after adapting to a competitive norm it was more difficult to unlearn this behavioural tendency. In my final experimental chapter, I assess behaviour on this task in adolescents. Given that adolescents appear to be more attuned to and more willing to adapt to social norms, I was interested to see if they would show greater adaptation on this task and whether this ability to adapt to social norms would facilitate social network gain from exploration.

Adolescent mental health and self-concept development

For those who will develop a mental health problem, their condition will likely onset during adolescence (Kessler, Angermeyer, et al., 2007; Solmi et al., 2022). Half of all lifetime mental health conditions start by age 14 and three quarters by age 24 (Kessler, Angermeyer, et al., 2007). Internalizing disorders in particular, such as anxiety and depression, often emerge during adolescence, with prevalence particularly high in girls (Hankin et al., 1998; Salk et al., 2017; Solmi et al., 2022).

Experiencing depression during adolescence carries significant consequences. Earlier age of onset is association with prolonged episode duration (Lewinsohn et al., 1994). Moreover, adolescent-onset depression is associated with a range of poor long-term outcomes from peer and family relationships, physical health problems, health-risking behaviours and impediments to educational and occupational attainment (Birmaher et al., 2002; Chang & Kuhlman, 2022).

The NHS Mental Health of Children and Young People in England survey has shown that prevalence of mental disorder in 5–15-year-olds rose from 9.7% in 1999 and 10.1% in 2004 to 11.2% in 2017. This could reflect a true increase in prevalence driven by a myriad of factors e.g. poorer economic environment following the 2008 crash; but could also reflect an increase in measured rather than actual prevalence due to e.g. reduction in stigma and increased awareness. The majority of this increase was due to increase in 'emotional disorders', including anxiety and mood disorders (Ford et al., 2020). Given the substantial social and economic costs associated with mental health conditions during adolescence (Kessler, 2012) and their apparent increasing prevalence, there is a clear imperative to prioritize the study of the mechanisms driving mental illness during this critical developmental period.

Mental health and the self

The way that people reflect on themselves is central to mental health. Classical cognitive models of depression, such as Beck's cognitive triad, include negative self-views as a core feature of depressive symptoms (Braet et al., 2015; Marchetti & Pössel, 2022). Furthermore, network analysis of adolescent depressive symptoms shows that self-hatred is a central symptom of adolescent depression, and reveals a strong connection between self-deprecation and self-blame symptoms (Mullarkey et al., 2019a). This suggests that self-views may play a central role in depressive symptomatology in adolescent depression, and that prioritizing these symptoms (along with other central symptoms) in theoretical models of adolescent depression could guide us to important treatment targets.

Multiple studies have emphasized the significance of self-esteem for mental health, which encompasses the evaluative and affective dimensions of self-concept and reflects an individual's sense of worth or value (Harter, 1990; Neff, 2011). High self-esteem is a fundamental characteristic of good mental health (Neff, 2011) and is also recognized as a protective factor that can buffer against the negative impacts of various stressors (Greenberg et al., 1992; Penninx et al., 1998).

Previous research has suggested that low self-esteem is a key vulnerability factor for the onset of depression during adolescence, supported by both cross-sectional and longitudinal data (Orth et al., 2008a; Sowislo & Orth, 2013). Therefore, the way we appraise our self-concept and form judgements about ourselves during adolescence may be a potential target for preventative interventions to promote mental health in adolescence.

Self-relevant cognition and mental health

Metacognition

Recent evidence has demonstrated distortions in metacognitive judgements related to psychiatric symptoms, independent of cognitive performance (Rouault, Seow, et al., 2018). Rouault et al. (2018) measured metacognitive sensitivity and overall confidence using a calibrated perceptual decision-making task (similar to Weil et al., 2018), during which participants were asked to decide which of two patches contained more dots and rated their confidence in each choice. Participants also completed multiple mental health questionnaires covering depression, anxiety, schizotypy, impulsivity, social anxiety, apathy, eating disorders and alcoholism. The authors then applied item-level factor analysis to obtain a parsimonious latent structure comprising three factors: anxious-depression; compulsivity and intrusive thoughts; and social withdrawal. Variability in the anxious-depression factor was associated with lower confidence in perceptual decision-making performance and greater metacognitive efficiency (albeit the latter result did not survive correction for multiple comparisons). In contrast, the compulsivity and intrusive thoughts factor was associated with greater confidence, suggesting that different dimensions of mental health are related to different cognitive vulnerabilities (Rouault et al., 2018).

Some researchers have suggested that local confidence judgements may be the lowest level of a hierarchical structure, from local confidence judgements (about a single decision), to global confidence (about performance more generally) and to higher-order traits such as self-beliefs. Recently, research has started to investigate the relationships between these different hierarchical levels of self-judgements and their associations with psychopathology. In one study (Hoven et al., 2023), participants were asked to complete a perceptual decision-making task. In this study, the task varied on two dimensions: difficulty (either easy or difficult, by varying the difference in dots between the patches) and veridical feedback (trial-by-trial feedback or no feedback). Two task types were randomly paired within each block. Participants were asked to make confidence judgements after each trial in the no-feedback tasks (measuring local confidence); they were also asked to rate their confidence in their overall performance on each of the two games at the end of each block (global confidence); and self-beliefs were measured using a single latent factor that was calculated through factor analysis on questionnaires measuring self-esteem, mastery, autonomy and self-efficacy. Interestingly, the same anxious-depression dimension reported above was related to lower local *and* global confidence, but the strongest association with mental health was the self-beliefs dimension (although this might be expected simply due to measurement similarity between mental health and self-beliefs compared with task confidence). Self-beliefs were also positively related to confidence at both global and local levels, but unrelated to task performance. The authors suggest this pattern of results suggests that self-beliefs may function as a prior informing lower levels of confidence judgements; however, it may also be the case that lower levels of confidence judgements form the foundations for self-beliefs.

Despite the above advances in the understanding of the relationships between mental health and metacognition, there have not yet been any investigations into metacognitive confidence and mental health symptom dimensions in adolescents.

Self-appraisals and self-referential memory biases

While healthy individuals tend to show a positive bias in self-appraisals, endorsing more positive than negative words about the self, depressive symptoms have been associated with a negative bias in adults (Davey et al., 2017) and in young people (Ke et al., 2018).

Interestingly, when asking depressed participants to make temporal judgements about themselves they judged their past and future selves as being elevated compared to their current self (Sokol & Serper, 2017); whereas for non-depressed participants, past selves were judged more harshly than current selves and current selves were judged more harshly than future selves. The observed optimism that depressed participants showed about their future selves in this study is interesting as it appears to be contrary to Beck's proposal of negative views of the future, although it might serve to further instantiate negative self-views while in a depressive state, if all other self-states are viewed more positively than the current (Sokol & Serper, 2017).

A meta-analysis has shown that recall of self-relevant information is negatively biased in participants with depression (Gaddy & Ingram, 2014), with depressed participants more likely to recall negative than positive self-judged words. However, results are not uniform across adolescent studies. The pattern of positive and negative memory bias appears to depend on the methods used (free recall versus recognition: Neshat-Doost et al., 1998). In some studies lower recall of positive self-referenced words (rather than greater recall of negative self-referenced words) was associated with greater depressive symptoms in young people (Gençöz et al., 2001). In other studies, depressed young people showed enhanced recall of negative adjectives (Zupan et al., 1987). Other studies have found that depressed children showed no bias compared with healthy children who displayed a positive bias in recall of self-referenced words (Hammen & Zupan, 1984a). Other studies have shown no group differences in free recall between depressed and non-depressed youth (Timbremont et al., 2008). In one study, children with a lower recall of positive self-referenced words at age 6 showed greater depressive symptoms at age 9, but depressive symptoms at age 6 did not predict self-referenced words recall at age 9 (Goldstein et al., 2015), consistent with negative self-referential bias acting as a risk factor for development of depression in young people (Platt et al., 2017). Further research is needed to unpick the effects of age, depression status, context and task design on positive and negative biases in self-referential memory.

McArthur et al. (2019) investigated the effect of self-reference and valence on memory across adolescence. They used what they termed a self-schema measure: a positive self-schema score (referring to the proportion of positive words both rated as self-descriptive and subsequently recalled, relative to all words rated as self-descriptive), and a negative self-schema score (derived in the same way using negative words; McArthur et al., 2019). They showed that negative self-schema showed an inverted U-shaped relationship with age, peaking around age

17, whereas positive self-schema stayed relatively stable with age. However, they did not measure depressive symptoms. It is interesting to consider whether changes to self-appraisal and self-referential memory biases over adolescence are reflective of a typical developmental trajectory or whether they are reflective of unmeasured depressive symptoms (which usually onset during adolescence, Solmi et al., 2022).

Exploration and autonomy

In the laboratory, there have been mixed results in the association between depression, anxiety and exploratory behaviour. Some studies have demonstrated a tendency for greater exploration in individuals with depression and anxiety. For instance, in a bandit-like task involving choices between options of varying values in a volatile environment, depressive symptoms were found to be associated with greater exploration (Blanco et al., 2013). Similarly, trait anxiety was positively linked to exploratory behaviour, and overall performance on the task followed an inverted U-shaped pattern, whereby moderate levels of anxiety and associated exploration led to the highest levels of performance whereas lower and higher levels of anxiety and associated exploration led to worse performance (Aberg et al., 2022). One possibility is that the positive association between anxiety and exploration may be driven by a heightened motivation to reduce uncertainty, although owing to the task design it is difficult to resolve directed (uncertainty-weighted, information-seeking) and undirected (random) exploration. A recent study using more sophisticated task revealed lower directed exploration in individuals with higher levels of trait somatic anxiety (Fan et al., 2023).

Investigating real-world exploration adds further layers of complexity, as it can be influenced by multiple factors: some that overlap with lab-based exploratory measures, such as uncertainty reduction and information seeking, but also others such as obligations (e.g. work, school, obtaining household supplies), socialising or exercise. Therefore, unpicking the factors underlying real-world exploration is even more complicated, especially since these factors may also impact mental health symptoms themselves.

There has been growing interest in leveraging technological advancements in mental health research, particularly in measuring real-world exploration using geolocation data from mobile phones. This approach holds promise due to its accessibility, as almost everyone in Western societies possesses a mobile phone. Consequently, researchers can now examine the associations between real-world exploration and mental health symptoms. Several studies have investigated this relationship in adults, typically demonstrating lower real-world exploration associated with mental health difficulties using various geolocation metrics. For example, Saeb et al., (2015) showed that depressive symptom severity was related to entropy (mobility between favourite locations) and location variance (GPS mobility independent of locations). The authors were also able to distinguish participants with depressive symptoms using a classifier on the normalized entropy feature of GPS data at around 86.5% accuracy. However, no studies have explored the associations between mental health and real-world exploration in adolescent samples.

Social functioning

Depression is often associated with changes to social functioning, especially social withdrawal (Kupferberg et al., 2016). Developmentally, social rejection and peer victimisation during childhood and adolescence are associated with poor mental health outcomes. For example, a large longitudinal study reported that being frequently victimised by peers at age 13 was associated with more than twofold increased in their odds of developing depression at age 18 (Bowes et al., 2015). This longitudinal association has been replicated by a number of studies for both depression and anxiety risk (Stapinski et al., 2014; Takizawa et al., 2014). This relationship is complex and may be bi-directional, as other studies have found that adolescent-onset depression is associated with altered social functioning in middle adulthood (Chang & Kuhlman, 2022). This finding exemplifies the importance of intimate friendships and building social networks during adolescence for wellbeing.

Individual differences in sensitivity to social rejection have been shown to be associated with depressive symptomatology (Platt et al., 2013). Some theorists have suggested that some depressive states may emerge as an adaptive, temporary response to perceived or anticipated social rejection (Allen & Badcock, 2003). This may lead individuals to withdraw from their social group to avoid further damage to their reputation or social status (Allen & Badcock, 2003). Therefore, sensitivity to social group dynamics could lead to both positive and negative outcomes: on the one hand, the ability to learn and adapt to social norms could facilitate relationship formation; on the other hand, when in the context of rejection, being hyper-sensitive to social rejection and one's social standing may lead to excessive withdrawal and depressive symptomatology.

Research Gap and Rationale

Few studies have brought together cognitive developmental and mental health research to investigate the cognitive mechanisms underlying self-concept construction in adolescence, the development of independent decision-making capacities and how these processes might be affected by symptoms of depression and anxiety.

In my thesis, I aimed to assess the development of four cognitive processes relevant to self-concept development: 1) how young people develop the ability to accurately reflect upon their own abilities; 2) how young people gather information about self-relevant attributes and objects; 3) how young people refine and gain certainty over their estimates of their own preferences and 4) how young people explore their environment, gain autonomy and build independent social networks.

Through this set of experiments, I aimed to capture some of the processes adolescents might use in order to construct their sense of self and to develop into autonomous adults.

Research questions and hypotheses

Experimental Study 1: Metacognitive efficiency and the ability to ignore false advice in adolescence

In my first study, I aimed to capture the development of metacognitive abilities across adolescence and how this relates to better independent decision making through the ability to ignore false advice from others. Furthermore, I also explored whether these (meta)cognitive processes were related to symptoms of depression and anxiety. Young people aged 8–9, 12–13 and 16–17 took part in the study. In order to measure metacognitive ability in a way that would engage this age group, I created the “Space Explorer” task, in which I used engaging stimuli to ask participants to make perceptual decisions, rate their confidence in the choice and decided whether or not to follow advice. Through this I could measure: participants’ overall confidence and metacognitive efficiency, i.e. how well participants’ confidence (Type II) judgements matched their performance, while controlling for (Type I) performance; and participants’ incorporation of helpful and false advice, an important component of independent decision making. I hypothesised that the ability to accurately reflect on the accuracy of decisions would continue to develop into adolescence and that this would support greater ability to ignore false advice but still take on helpful advice. I also predicted that I would observe the same pattern of associations between metacognition and mental health symptom as observed previously (Rouault, Seow, et al., 2018)

Experimental Study 2: Impact of valence on self-appraisals and memory in adolescence

In the next study, I investigated the self-reference effect (SRE) as a mechanism for self-relevant information gathering in adolescence. I used a self-reference task with valenced words, so that I could also assess the impact of valence on memory across adolescence. 11–30-year-olds were asked to judge how well multiple adjectives described themselves or a chosen other person (fictional character or famous figure) and were later given a recognition memory test for these words.

I hypothesised that the youngest participants would be the most motivated to develop their self-concept and would perceive stimuli related to themselves as particularly significant. Therefore, I anticipated that the youngest participants would exhibit the most pronounced SRE, demonstrating a greater disparity in recognizing words judged in reference to themselves compared to those judged in reference to others. Additionally, I predicted that the magnitude of the SRE would decline as participants transitioned into adulthood, at which point self-concept is assumed to become more stable. Drawing on existing literature, I also hypothesized that negative self-judgments would increase during adolescence and decrease as individuals enter adulthood.

Experimental Study 3: How do adolescents develop a sense of their own preferences?

After investigating information-gathering mechanisms for self-relevant traits, I turned to the question of how adolescents develop their estimates of their own preferences: moving from asking how we develop our estimates of “what we’re like” to “what we like”. I was interested in whether the process of making choices in and of itself could allow adolescents to refine their sense of their own preferences. I was inspired by observing the mass popularity of quizzes about the self on Buzzfeed's website, in which young people especially appear to enjoy answering questions about their own preferences.

I tested whether adolescents aged 11–18 could use the process of choosing itself to refine their value estimates. I was also interested in whether this value refinement would be experienced as rewarding. Thus, I designed two tasks task, in which I could assess value refinement, and the amount of monetary reward adolescents were willing to forgo to complete choices about their own preferences, respectively.

I predicted that younger adolescents would show the largest refinement of their preferences through choice, since they would be the most uncertain about their preferences to begin with (and would therefore "benefit" from making choices the most), and that this would reduce across adolescence. I predicted that this uncertainty reduction would be rewarding and therefore that younger adolescents would be more willing to forgo monetary reward to complete self-preference choices than older adolescents. Finally, I predicted that depressive symptoms would disrupt this process, in that adolescents with greater depressive symptoms would show lower value refinement through choice and would therefore be less willing to forgo monetary reward in order to make choices.

Experimental Study 4: Real-world exploration, autonomy, affect and social network building in adolescence

In my final study I aimed to build on previous work to investigate how real-world exploration could promote adolescent independence. I designed a study with university "freshmen", entering their first year of study (aged 17–19) and younger adolescents entering a new high school (aged 13-15). This provided the opportunity to study how real-world exploration was associated with affect (positive and negative), additions to young people's social networks and feelings of autonomy at this formative transitional stage. I also investigated whether social functioning (adaptation to social norms) and mental health mediated the relationships between exploration and social and affective outcomes.

I tested multiple hypotheses: 1) that roaming entropy would be related to positive affect and additions to social contacts; 2) that roaming entropy would be higher in the older adolescents (university students) compared to the younger adolescents (high schoolers); 3) that the relationship between roaming entropy and positive affect would be modulated by feelings of autonomy; 4) that poor mental health would be associated with lower roaming entropy and fewer new social contacts and that poor mental health would disrupt the associations between roaming entropy and positive affect and roaming entropy and social network gain; and 5) that social norm adaptation would facilitate the relationship between roaming entropy and social network gain.

Chapter 2

Statistical Methods

Statistical models

For Chapters 4 to 6, I analysed data using mixed-effects models, allowing me to use trial-level as oppose to aggregate data and group error terms by items or by participant (Bates et al., 2015).

Trial-level data was modelled using mixed-effects models with the *lme4* package in R (Bates et al., 2015; R Core Team, 2014). Continuous outcomes (e.g. ratings, reaction times (RTs)) were investigated with linear mixed-effects models, while categorical outcomes (e.g. accuracy) were investigated using a generalised linear mixed-effect model and a logit link function (i.e. logistic regression).

Where possible, I employed maximal random slopes for the within-subject factors (Barr, 2013). In some models, maximal random slopes led to a singular model fit. This failure to converge is common in models with greater complexity and is taken as an indication that the model is over-specified. In these cases, I simplified the random slopes structure by removing the interactions between random slopes (as suggested by Barr, 2013) or removing the random slopes altogether, allowing the model to converge.

I report main effects and interactions of the best-fitting models using omnibus Type III χ^2 Wald tests. These were further probed with planned and post-hoc comparisons using the emmeans package (Lenth et al., 2020), which were Bonferroni corrected for multiple comparisons.

For Chapter 3, analysing trial-level data was not possible because I was interested in aggregate measures: metacognitive bias and metacognitive sensitivity or efficiency (meta-d’, meta-d’/d’). Therefore, data was analysed using the standard summary statistics approach, and individual differences tests were conducted using linear regression in MATLAB.

Model comparison approach

For Chapters 3 to 5, I compared various functions of age, namely linear, quadratic, cubic, their nested polynomials (i.e. linear + quadratic, linear + quadratic + cubic), inverse, logarithmic, exponential and emergent age (see Chapter 3) (Luna et al., 2004), and selected the model with the lowest Bayesian Information Criteria (BIC) . If this was achieved by a polynomial model (linear + quadratic + cubic), I further compared this to the next lower-level model via nested model comparison (i.e. ANOVA; (Bates et al., 2015), progressively removing higher order polynomials if these did not explain significantly more variance.

Chapter 3

Emerging metacognition allows adolescents to ignore false advice

Part of this chapter has been published as:

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Abstract

Adolescents aspire to independence. Successful independence means knowing when to rely on one's own knowledge and when to listen to others. A critical prerequisite is thus a well-developed metacognitive ability to accurately assess the quality of one's own knowledge. Little is known about whether the strive to become an independent decision-maker in adolescence is underpinned by the necessary metacognitive skills. Here, I demonstrate that metacognition matures from childhood to adolescence (N=107) and that this process coincides with greater independent decision making. I show that adolescents, in contrast to children, take on others' advice less often, but only when the advice is misleading. Finally, I demonstrate that adolescents' reduced reliance on others' advice is explained by their increased metacognitive skills, suggesting that a developing ability to introspect may support independent decision making in adolescence.

Introduction

Adolescents strive for independence and are often accused of not listening to their parents' advice. According to Socrates, "they have bad manners, contempt for authority; […] they contradict their parents […] and tyrannize their teachers" (Patty & Johnson, 1953). Today's stereotypes about teenagers often echo this sentiment that teenagers are indignant towards the wishes of their parents or teachers (Stern, 2005). Known as the 'separation-individuation' arbitration (Koepke & Denissen, 2012a), adolescence is a time when becoming independent from one's parents is particularly pertinent, as adolescents exert increasing control over their own decisions.

Becoming an independent decision maker is an important step towards full adult autonomy. However, resistance to authority (Kuhn & Laird, 2011) and increased risk-taking behaviours (Duell et al., 2018) during this period have led to the assumption that adolescents still lack the necessary abilities for making good independent decisions. This stands, at least in part, in contrast to legal and constitutional rights that allow adolescents to make independent decisions without consulting others first (relating to e.g. medical treatment decisions, online privacy consenting, driving and voting). What are the cognitive processes that enable us to become independent and good decision makers, and when do they develop?

An important part of being an independent decision-maker is the ability to accurately judge one's previous decisions (Batha & Carroll, 2007; Yeung & Summerfield, 2012). This metacognitive ability – the ability to accurately introspect on one's own decisions (Koriat, 2007) – is critical when deciding how much to rely on one's own decisions or on the advice of others (Fiedler et al., 2019). One common procedure for assessing metacognition is to ask participants for confidence judgements about their own performance in the absence of feedback. Previous work has indicated that children as young as three years old have some metacognitive ability, in that they are more confident when correct than when incorrect (Lyons & Ghetti, 2011). Substantial prior work suggests that this distinction may continue to improve during childhood and into early adolescence, as children's confidence ratings become better aligned to their actual performance (Fandakova et al., 2017; Hembacher & Ghetti, 2013; C. M. Roebers et al., 2004). However, fewer studies have assessed the continued development of metacognitive ability across adolescence (Brackmann et al., 2019; Weil et al., 2013).

In addition, independent decisions require the ability to utilize confidence signals to monitor behaviour, for example, deciding when to seek further information or help from others and when to incorporate (or ignore) such information. Previous work has shown that young children and even infants may be able to utilize their confidence in their own and others' decisions to know when to ask for help (Coughlin et al., 2015; Goupil et al., 2016; Koenig & Harris, 2005; Lyons & Ghetti, 2011). Moreover, young children appear to be able to monitor the accuracy of advisors and accurately identify the reliable advisor among multiple advisors (Koenig & Harris, 2005). However, they may be misled when given false advice that contradicts their *own* decision or knowledge and, in such a scenario, often only ignore testimony from others when they can be highly confident in their own beliefs (Jaswal, 2010; Jaswal et al., 2010). As children approach adolescence, they become better able to arbitrate between recommendations from others and their own beliefs (Selmeczy & Ghetti, 2019), but may still be misled when information is not helpful (Roebers, 2002; Roebers & Howie, 2003; Schwarz & Roebers, 2006).

Evidence in probabilistic learning contexts suggests that adolescents perform similarly to (or sometimes better than; Decker et al., 2015) adults when they need to ignore false advice from others (Lourenc et al., 2015). In such paradigms, a participant is typically given a single instance of helpful or misleading advice at the beginning of the task before learning for themselves the value of a set of options (Decker et al., 2015; Lourenc et al., 2015; Rodriguez Buritica et al., 2019). This design may better capture the influence of increased exploration in adolescence, rather than advice-taking behaviour *per se*, as participants can quickly determine the (in)validity of the advice by exploring other non-advised options (Rodriguez Buritica et al., 2019).

In the current study, I exploited methodological advances in the measurement of metacognition (Fleming & Lau, 2014; Maniscalco & Lau, 2012, 2014), which allow the distinction between participants' overall confidence (metacognitive bias) and ability to track performance (metacognitive sensitivity). Metacognitive bias and sensitivity have often been conflated previously but may reflect different psychological phenomena (Hauser et al., 2017; Moses-Payne et al., 2019; Rollwage et al., 2018; Rouault, Seow, et al., 2018). I use a signal detection theory framework in the context of a simple perceptual discrimination task, which helps us to better tease apart these constructs and assess their relative contribution to development (Fleming & Lau, 2014; Maniscalco & Lau, 2012, 2014). Such an approach has been used previously with infants, adolescents and adults (Fandakova et al., 2017; Goupil et al., 2016; Goupil & Kouider, 2016; Salles et al., 2016; Weil et al., 2013), but still little is known about how metacognitive bias and sensitivity relate to advice taking.

A number of previous studies have investigated the relationship between mental health symptoms and metacognitive variables in adults. For example, using an unselected sample, Rouault et al. (2018) showed that an "anxious-depression" symptom factor was associated with lower metacognitive bias and higher metacognitive efficiency (although the latter result did not survive corrections for multiple comparisons). Furthermore, I previously found that greater post-decision evidence integration, a similar process to advice-taking whereby participants must incorporate new evidence presented after a decision, is associated with greater depressive symptoms (Moses-Payne et al., 2019). However, there have not yet been any investigations into the associations between metacognitive variables and mental health symptoms in developing populations. Therefore, I conducted an exploratory analysis to investigate these associations in the current study.

I designed a novel paradigm which controls for, potentially confounding, individual differences in perceptual ability by titrating Type I performance using a staircase procedure (Cornsweet, 1962; Fleming et al., 2010; García-Pérez, 1998; Levitt, 1971). The task was adapted for use in children, using the framing of planets with alien populations, to help increase accessibility and engagement. Further, during the analysis I use metacognitive 'efficiency' (Fleming & Lau, 2014; Maniscalco & Lau, 2012, 2014) as a measure of how well participants' confidence tracked their performance, which also accounts for any differences in the level of true performance (often overlooked in previous research). This metacognition task design was paired with advice from a 'space advisor' and helpful advice was contrasted with misleading advice at trial-level. Advice was given after a decision had already been reached in order to assess changes of mind, which may be more tightly linked to metacognitive evaluations (C. D. Frith, 2012; Hauser et al., 2017; Koriat, 2012; Moran et al., 2015; Rollwage et al., 2018; Yeung & Summerfield, 2012).

By combining metacognition and advice taking in one task, I was able to investigate how young people can utilize their emerging metacognitive abilities to arbitrate helpful from misleading advice. I assessed the interaction between confidence and advice taking in 8–9-year-olds, 12–

13-year-olds and 16–17-year-olds to investigate the protracted development of metacognitive ability and advice taking into the teenage years. I predicted that metacognitive efficiency would show age-related improvement and that increased metacognitive efficiency would be related to increased ability to ignore false advice. I also explored the associations between these task variables and depression and anxiety symptoms, predicting that children and adolescents would show a similar pattern to adults in previous studies, in that depression and anxiety related to lower metacognitive bias and higher metacognitive efficiency.

Methods

Participants

I recruited participants from schools across London, UK. For participants under the age of 16, I gained parental and participant consent. Participants over the age of 16 consented to take part themselves. Participants were given a voucher valued at £7.00 for their participation and no aspects of the tasks were explicitly incentivized with monetary gain, consistent with previous work (Fandakova et al., 2017; Weil et al., 2013). The study was approved by the Research Ethics Committee of University College London (study number: 14261/001).

I tested 108 participants and analysed the data from 107 participants. One participant was excluded due to a pre-existing neurological condition. Out of 107 participants, 45 were male and 62 were female. I recruited participants in three age groups: age 8–9 (i.e. 8.89–9.71, mean age ± SD: 9.34 ± .27, n=30, male/female n=11/19), age 12–13 (i.e. 12.69–13.70, mean age ± SD: 13.13 ± .30, n=41, m/f n=19/22) and age 16–17 (i.e. 16.71–17.76, mean age ± SD: 17.19 ± .29, n=36, m/f n=15/21). This age range was selected to span pre-, early- and mid-adolescence. It was also selected with a one-year longitudinal follow-up in mind, using an accelerated longitudinal design, which I was unable to complete because the testing was scheduled for March 2020 during the Covid-19 lockdown. The age groups did not differ in IQ (See Table 1).

Our power calculations based on previous related studies (Decker et al., 2015; Hauser et al., 2017; Lourenc et al., 2015; Selmeczy & Ghetti, 2019; Weil et al., 2013) suggested a sample size of ~30 per group would be sufficient to detect medium size effects (f^2=.15) with 80% power. I optimized power analysis to detect age differences in my main dependent variables (metacognitive bias and sensitivity, advice taking), as this was my primary analysis of interest.

I did not conduct a power analysis for the mediation analysis, as this was a secondary analysis. Previous studies have suggested that mediation effects can be detected in a similar design with smaller samples than included in the current study (Rollwage et al., 2020), but other studies suggest that substantially larger sample sizes are required (Fritz & MacKinnon, 2007; Schoemann et al., 2017).

To counteract the currently dominant recruitment bias towards higher socio-economic status young people (Fakkel et al., 2020), I deliberately selected schools in socially diverse and disadvantaged areas. In participating schools, the proportion of pupils eligible for pupil premium (additional funding for children in local authority care or those known to be eligible for free school meals), with English as an additional language and from minority ethnic backgrounds was above or well above the national average according to Ofsted reports (Office for Standards in Education, 2013-15).

Table 3.1 **Participant demographics.**

	8–9-year-olds (n = 30)	**12–13-year-olds** (n = 41)	**16–17-year-olds** (n = 36)	
Age mean ± SD	9.34 ± .27	13.13 ± .30	17.19 ± .29	*NA*
Sex m/f	11/19	19/22	15/21	$\chi^2(2) = .67$, $p = .716$.
IQ (WASI-II) mean ± SD	93.87 ± 13.44	98.51 ± 13.45	97.22 ± 10.26	$F(2,104) = 1.24$, $\eta_p^2 = .02$, $p = .294$

Note. Age, sex and IQ scores for the three age groups: 8–9-year-olds, 12–13-year-olds and 16–17-year-olds. Statistical tests of the difference between groups are reported where applicable.

Overview of procedure

Participants were introduced to the Space Explorer task and given both verbal and written instructions. Participants also completed three other tasks, mental health questionnaires (other tasks and questionnaires reported elsewhere: Bowler et al., 2021; Dubois et al., 2022), and the Wechsler Abbreviated Scale of Intelligence verbal and abstract reasoning tests, version II (Wechsler, 1991; WASI-II). Participants were tested in groups of three to four in a quiet room with two experimenters present. The order in which participants completed the tasks, questionnaires and WASI-II was pseudo-randomised between participants. In total, the adolescent participants (12–13 years, 16–17 years) spent ~1.5 hours completing the experiment. The youngest participants (8–9 years) completed the experiment over two sessions to reduce fatigue (however, the Space Explorer task was always completed within a single session), and spent ~2 hours completing the experiment.

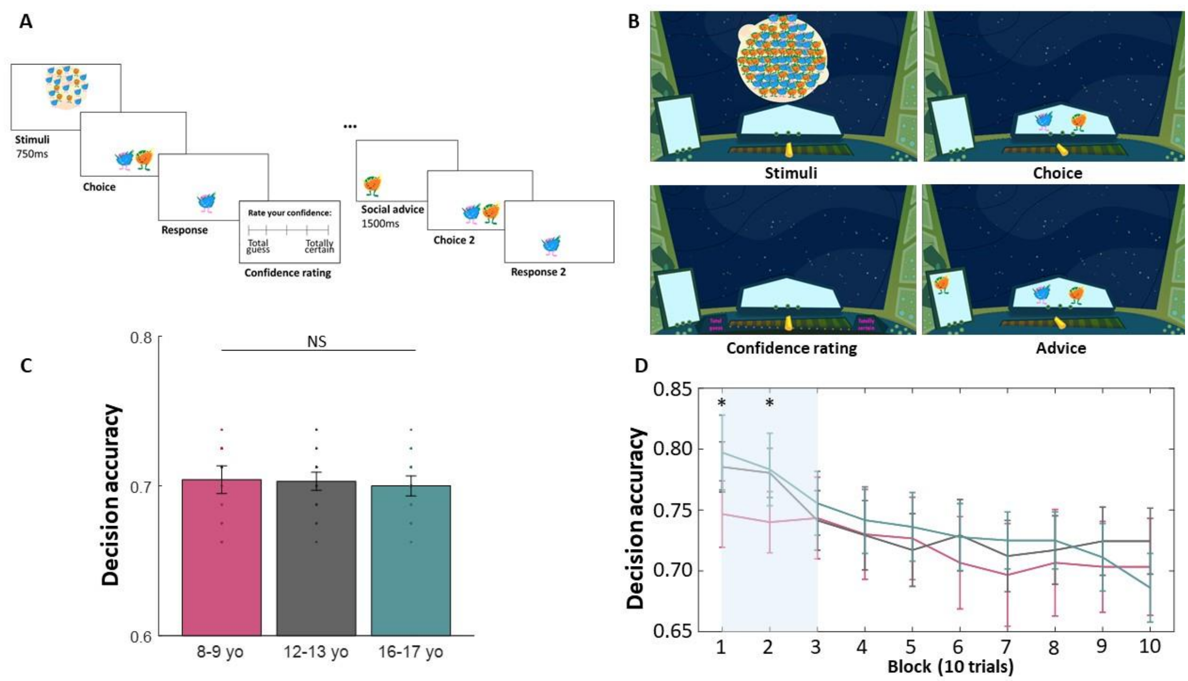
Experimental Design

Space Explorer task.

Stimuli. The Space Explorer task was programmed in Cogent 2000 (MATLAB toolbox, http://www.vislab.ucl.ac.uk/cogent_2000.php). Participants viewed a spaceship cockpit, within which were two display screens (one central for displaying choice, one to the side for displaying advice) and a confidence slider (displayed only during confidence reports; Fig. 3.1B).

Stimuli for the perceptual decision consisted of a planet, presented briefly in the center of the screen with 68 aliens displayed in a circle formation over the top of the planet. There were eight possible alien colours (selected to be easily discriminated between, even by participants with colour blindness) but on each trial two different colour aliens were randomly selected. Aliens were identical apart from differences in colour. There was always more of one colour alien than the other, the exact difference in number was calibrated to individual participants based on a staircase procedure to ensure equal performance (see below). After stimulus presentation, an example of the two aliens was displayed on the left and right of the central display screen for participants to make their choice.

Figure 3.1 Probing advice taking in metacognition.



Note: I developed a novel task that allowed the assessment of the development of metacognition and advice taking. (a) Participants viewed an array of two different coloured aliens for 750 ms, were asked to indicate which colour was more plentiful and rated their confidence in their decision. Subsequently, participants received advice from a 'space advisor', and had the opportunity to revise their choice. All decisions and confidence ratings were self-paced. (b) The participants viewed a spaceship cockpit with two screens that displayed instructions, choices (middle screen) and advice (left screen) through the task. The planets were displayed through the cockpit 'window'. (c) Task performance was staircased to achieve equal performance for all participants. Mean decision accuracy did not differ between age groups and was well calibrated to ~70% accuracy. Mean accuracy was very similar (NS, nonsignificant) across age groups (8–9-years-old [yo] M = 70.42; 12–13yo M = 70.30; 16–17yo M = 70.00). (d) Decision accuracy by blocks of 10 trials (colours represent age groups as in c). Shaded area indicates initial practice trials without confidence ratings that were excluded from any analysis. Error bars represent 95% confidence intervals. *$p < 0.05$ uncorrected

Task procedure. In the Space Explorer task, participants were first asked to make a perceptual decision based on an array of two different colour aliens presented for 750ms. Participants were instructed to decide as quickly as possible (‘as quickly as you can’), which of the two aliens there was more of and log their response by key press.

This was followed by a confidence rating. Participants rated their confidence on a sliding scale from ‘total guess’ to ‘totally certain’, labels that were chosen after piloting to ensure the youngest participants would comprehend the scale. Participants were instructed to use the entire length of the scale.

In half of the trials, this was then followed by advice from a space advisor. The advised answer (an image of one alien) was displayed to participants for 1500ms in a small ‘messenger screen’. Participants were then given the option to revise their initial choice and rerated their confidence. The advice was correct on 70% of trials, thus matching the participants’ performance. This level of accuracy of advice was chosen in order to avoid stereotyped responses from the participant (e.g. advice that is totally accurate may lead participants to always follow advice and ignore their own choices, whereas advice that is chance-level may lead to participants completely ignoring advice). The trials on which advice was given and on which the advice was correct or incorrect (70% correct trials) were randomly determined. Participants were verbally instructed that ‘the advisor should be correct most of the time but can also make mistakes' (and reiterated in the written instructions, given by a masked astronaut) 'the advisor should be correct most of the time, but they're only human, so can make mistakes just like you and I!', but were not given any indication of any other characteristics of the advisor.

For the practice trials (first 30 trials), participants simply made the perceptual decision and were given feedback ('correct' vs 'incorrect'). These trials were included to allow the staircase to converge before starting the task (Fig. 3.1D). Feedback was given on practice trials in line with previous work (Moses-Payne et al., 2019; Rollwage et al., 2018), to allow faster convergence and so that experimenters could monitor performance to ensure participants understood the task. In the remaining trials (80 trials), participants were no longer given feedback but instead rated their confidence in their response. For half of these trials, participants received advice, revised their initial choice and rerated their confidence.

All pre- and post-advice decisions and confidence ratings were self-paced. In total, the Space Explorer task took 10-20 minutes to complete. For task procedure see Fig. 3.1A, for task interface see Fig. 3.1B.

Calibration. A staircase procedure was used throughout the task in order to match participants' performance. To this end, I used a 2-down-1-up staircase procedure with equal step sizes that converged at ~70% accuracy (Fleming et al., 2010; García-Pérez, 1998; Levitt, 1971) . This was used to identify the difference in aliens needed to elicit near-threshold performance (i.e. between chance and ceiling performance) for individual participants so as to elicit the most variation in confidence ratings (as previously, e.g. Fleming et al., 2010). The staircase could also account for any differences in speed-accuracy trade-offs between groups by adjusting evidence strength accordingly.

There was a starting point difference of 30 aliens between the colours (i.e. 49 colour A, 19 colour B) with a starting step size of ± 8 aliens which was halved after 10 reversals, halved again after 30 reversals, again after 50 and so on. The staircase was initiated during the 30 practice trials to minimize burn-in period and continued working throughout the task.

Mental health questionnaires

I measured depressive symptoms using the Mood and Feelings Questionnaire – Short Form (MFQ-SF; Sharp et al., 2006), which consists of 13 items. The MFQ-SF has been validated in 11–18-year-olds (Rhew et al., 2010; Sharp et al., 2006; Turner et al., 2014) for the measurement of depressive symptoms. The total score was used in analyses, and no participants were missing items. I measured anxiety symptoms using the Screen for Child Anxiety Related Disorders, also in short form, consisting of 10 items. The questionnaire was developed by Birmaher et al. (1999), who validated the scale in 9–18-year-olds, and shortened by Vigil-Colet et al. (2009), who validated the shortened version in 8–12-year-olds (Birmaher et al., 2002; Vigil Colet et al., 2009).

Statistical Analysis

Model comparison approach to analysis

The development of cognitive functions from childhood to adolescence does not always follow a simple linear trajectory with age (Jones et al., 2014; Nook et al., 2019; Somerville et al., 2013a, 2017; Van Den Bos et al., 2015). For this reason, I used a model comparison approach to compare between linear, quadratic and adolescent-emergent (appears in early adolescence and then plateaus) patterns of developmental differences. This approach has been used previously to better describe nonlinear patterns of development across this age range (Jones et al., 2014; Nook et al., 2019; Somerville et al., 2013a, 2017; Van Den Bos et al., 2015). Linear age was computed using Z-scored raw age; quadratic age was computed using the square of linear age; adolescent-emergent age was calculated using quadratic age but replacing values above 12 with the same value (Somerville et al., 2013a). For each analysis, I compared the model fit of these three models of age and the linear combinations (sums) thereof (seven models in total) using BIC to determine the best fitting model (See Table 2).

I report the winning model for each analysis using continuous transformed age and use subsequent independent t-tests to compare between age groups. I plot effects using age groups for interpretability. I also include sex as a covariate in all models, as previous research has suggested sex may be associated with confidence-based measures in adolescence (Weil et al., 2013). Although I report significant effects of sex where they were found, sex was not a main predictor variable of interest and I did not make any *a priori* hypotheses about sex. To compare performance across groups, I use ANOVA. I report effect sizes using Cohen's d and partial eta-squared where applicable.

Table 3.2 **Model comparison of different forms of age for each task metric.**

BIC	Linear	Quadratic	Emergent	L + Q	L + E	E + Q	L + Q + E
Meta bias	311.98	**307.09**	310.78	311.77	313.48	311.70	313.26
Meta-d’/d’	298.87	301.78	**298.12**	301.99	302.57	302.76	305.38
Advice taking	305.16	310.11	**303.78**	308.24	308.24	308.29	312.89
Resistance to false advice	309.92	308.61	**307.39**	311.45	311.71	311.55	316.09

Note. Values in bold represent the winning model. Meta bias – metacognitive bias, overall mean confidence. Meta-d’/d’ – metacognitive efficiency. Advice-taking – propensity to follow advice. Resist false ad – resistance to false advice.

Metacognitive bias and sensitivity

I calculated metacognitive bias (named in line with previous literature e.g. Fleming & Lau, 2014; Moses-Payne et al., 2019; Rouault et al., 2018) by taking the mean confidence rating across all trials in which confidence ratings were given. Given that basic task performance was equated between subjects, mean confidence ratings reveal between-subject 'bias' in subjective confidence (generally rating high or low confidence, irrespective of performance).

I calculated metacognitive efficiency (meta-d'/d') using signal detection theory approach and maximum likelihood estimation using a MATLAB (Maniscalco & Lau, 2014) function provided at http://www.columbia.edu/~bsm2105/type2sdt/). Meta-d' quantifies Type II metacognitive sensitivity (the degree to which participants' confidence ratings discriminate between correct and incorrect trials, or 'hits' – i.e. high confidence correct trials - minus 'false alarms' – i.e. high confidence incorrect trials) and so is expressed in the same units as Type 1 perceptual sensitivity, or d' (the degree to which participants can distinguish between different coloured aliens, or 'hits' correct alien selected minus 'false alarms' incorrect alien selected). Meta-d' can thus be thought of as the sensory evidence (both internal and external) available for metacognitive judgements in signal-to-noise ratio units, just as d' is thought of as the evidence available for decisions in signal-to-noise-ratio units.

Since hit and false alarm trials will not be normally distributed, a non-parametric analysis is used (receiver operating characteristic – ROC). ROC curves plot the proportion of high confidence trials when the participant is correct (hit rate) against the proportion of high confidence trials when the participant is incorrect (false alarm rate). To obtain the curve, confidence ratings are split by different criterion (e.g. low confidence = 1st bin, high confidence = bin 2-4, then low confidence = bin 1-2, high confidence = 3-4 and so on), for each split hit and false alarm rate are calculated and plotted to obtain the type II ROC curve. The area under the curve (AUROC) can be used as a measure of metacognitive sensitivity and the larger the area under the curve the higher participants' sensitivity. The issue with simple AUROC analysis is that it is affected by Type I performance (perceptual performance). This is where the model-based measures used here are useful, as they exploit the fact Type II performance is constrained by Type I performance i.e. if a participant performs at chance level on the perceptual decision it is impossible for them to have any metacognitive insight into their performance (Galvin et al., 2003). Therefore, using model approaches I can place strong constraints on the measure of metacognitive sensitivity allowing me to compare meta-d' and d' directly.

Metacognitive efficiency (meta-d'/d') is a relative measure that eliminates any remaining performance and response bias confounds (Barrett et al., 2013; Galvin et al., 2003; Maniscalco & Lau, 2012, 2014; Masson & Rotello, 2009). Perfect metacognition occurs when meta-d' and d' are matched and thus meta-d'/d' is 1.

Meta-d' is theoretically bounded at the lower end by zero, but when fit using an unbounded maximum likelihood procedure estimation error may lead to negative values in practice. This estimation error applies to all values but becomes evident when values fall outside the theoretical range (Fleming et al., 2014; Maniscalco & Lau, 2012). On these grounds, I did not see sufficient reason to remove or adjust negative values and report analyses including negative values. For completeness, however, I repeated analyses with negative meta-d' values (n=6) set to zero, which revealed the same pattern of results (data not shown). I also performed all analyses using metacognitive sensitivity (meta-d') rather than metacognitive efficiency and found the same pattern of results (data not shown). Three participants (aged 8–9) gave mostly extreme confidence ratings and thus their metacognitive sensitivity (and subsequently metacognitive efficiency) could not be estimated, these participants were thus not included in subsequent analyses that included metacognitive efficiency.

Advice taking and resistance to false advice

Overall propensity to follow advice was calculated by taking the proportion of trials that participants switched their choice when the advisor disagreed with them (divided by the total number of trials on which the advisor disagreed) minus the proportion of trials that participants switched their choice when the advisor agreed with them (divided by the total number of trials on which the advisor agreed). This was done to account for changes of mind that were not advice related.

Resistance to false advice was calculated by taking the proportion of trials on which participants followed helpful advice i.e. were incorrect and switched to the advised correct choice (divided by the total number of trials on which participants were incorrect and received conflicting advice) minus the proportion of trials in which participants followed false advice i.e. were correct and switched to the advised incorrect choice (divided by the total number of trials on which participants were correct and received conflicting advice). Therefore, a score of zero means that the participant did not discriminate between helpful and misleading advice in their second choice, a positive score means the participant followed helpful more than misleading advice and a negative score means the participant followed misleading more than helpful advice.

Both propensity to take advice and resistance to advice were standardized (Z-scored).

Mediation analysis

I used mediation analysis as a secondary analysis to assess whether the effect of age on resistance to false advice was mediated by metacognitive efficiency. I use standard notation to report mediation paths, where X represents the independent variable (adolescent-emergent age), Y represents the outcome variable (resistance to false advice) and M represents the mediating variable (metacognitive efficiency, meta-d'/d'). The *c* path defines the overall effect of X on Y or the total effect; *c'* defines the effect of X on Y controlling for M and represents the direct effect; *b* represents the effect of M on Y, controlling for X; *a* defines the effect of X on M and the product *ab* defines the indirect effect of X on Y through M.

I used the Mediation Toolbox in MATLAB (https://github.com/canlab/MediationToolbox; (Wager et al., 2008, 2009)) to perform the analysis. This toolbox is used to calculate mediation analysis based on a standard 3-variable path model (Baron & Kenny, 1986) with a bootstrap test for the statistical significance of the product *ab* (adjusted indirect effect of age on resistance to false advice; Efron & Tibshirani, 1986; Shrout & Bolger, 2002). I entered adolescent-emergent age as predictor variable, resistance to false advice (standardized) as the outcome variable, metacognitive efficiency (meta-d'/d', standardized) as the mediator and sex was entered as a covariate (as in all previous analyses). This toolbox tests the significance of *ab* using the accelerated, bias-corrected bootstrap test (Efron & Tibshirani, 1986; Shrout & Bolger, 2002) with 10,000 bootstrap samples to test each of the *a*, *b* and *ab* path coefficients. It is required that all three paths (*a*, *b* and *ab*) are significant in order to satisfy the conclusion that the covariance between adolescent-emergent age and resistance to false advice was explained by metacognitive efficiency.

Results

To test the hypothesis that advice taking during adolescent development is linked to improved metacognitive efficiency, I tested three age groups of participants, 8–9 years, 12–13 years and 16–17 years (selected to span pre-, early- and late-adolescence). Participants completed the Space Explorer task, in which they made perceptual decisions, rated their confidence in those decisions and, on some trials, were able to revise initial decisions after receiving advice.

Perceptual decision-making performance was matched across age groups

To assess participants' metacognitive abilities without bias due to differences in decision making performance, I used a staircase procedure in the task that enabled participants in each age group to achieve the same level of accuracy in their perceptual judgements. The staircase procedure was successful, as participants did not differ in their overall task performance (Fig. 3.1C; accuracy: $F(2,104) = 0.36$, $\eta_p^2 = .01$, $p = .701$; d': $F(2,104) = .05$, $\eta_p^2 = .001$, $p = .947$), nor at any point during the task (Fig. 3.1D).

Younger participants required a greater evidence difference (number of colour A aliens – number of colour B aliens, excluding practice trials) in order to detect the more plentiful alien at the same performance level as the older participants ($F(2) = 3.11$, $\eta_p^2 = .06$, $p = .049$; Winning model linear: $\beta = -.96$, $SE = .38$, $p = .013$). As all participants started at the same evidence level in the practice trials, this means that younger participants received a greater number of practice trials in which they were incorrect (and received 'incorrect' feedback; linear age: : $\beta = -.24$, $\eta_p^2 = .06$, $p = .013$; 8–9yo M ± SD = 8.33 ± .84; 12–13yo M ± SD = 8.02 ± .65; 16–17yo M ± SD = 7.89 ± .67; total practice trials = 30). Therefore, I analysed whether this increased negative feedback in the practice trials influenced confidence-related measures in the experimental trials. There was no evidence to suggest that the amount of negative feedback in the practice trials was associated with either i) overall confidence ($\beta = .03$, $SE = .09$, $t = .35$, $p = .725$; age and sex remain significant), or ii) metacognitive efficiency (feedback: $\beta = -.0004$, $SE = .05$, $t = -.01$, $p = .993$; age remains significant).

Age groups did not differ in IQ (measured by WASI-II, $F(2,104) = 1.24$, $\eta_p^2 = .02$, $p = .294$; See Table 3.1) and IQ did not relate to any task-based measures (decision accuracy: $\beta = .0008$, $SE = .002$, $t = .41$, $p = .685$; metacognitive efficiency: $\beta = .05$, $SE = .05$, $t = 1.13$, $p = .263$; propensity to follow advice: $\beta = -.14$, $SE = .09$, $t = -1.58$, $p = .117$; resistance to false advice: $\beta = .01$, $SE = .02$, $t = .49$, $p = .627$; all results remained consistent when controlling for IQ).

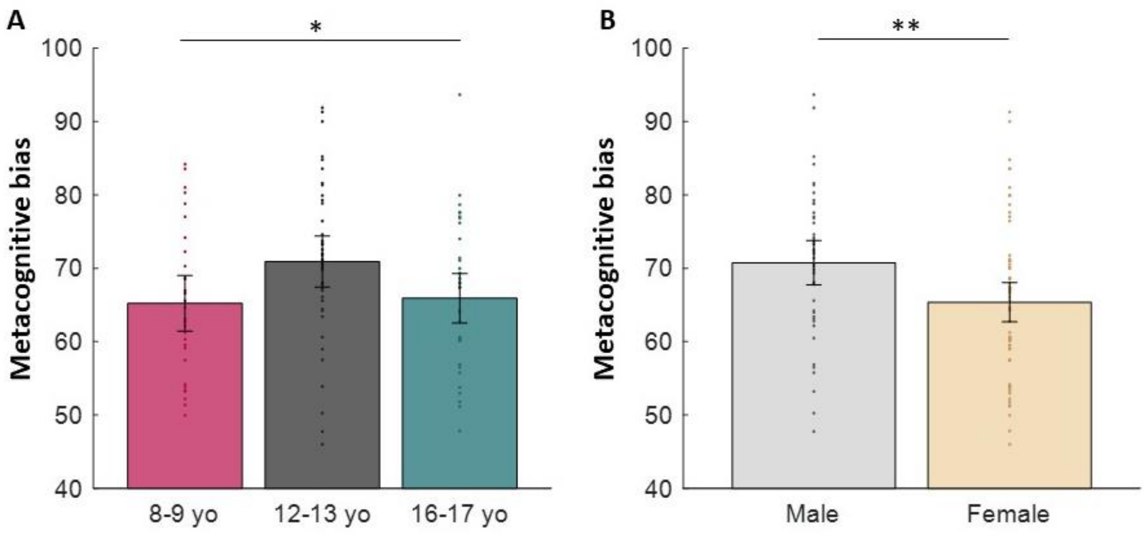
Young adolescents and males were most confident

All age groups appeared to use the scale in a similar way, in that confidence ratings were well distributed and were similarly variable across age groups (standard deviation of ratings: $F(2,104) = 1.63$, $\eta_p^2 = .03$, $p = .202$).

To assess participants' metacognitive bias, I examined the mean confidence score across all trials. Interestingly, I found that metacognitive bias peaked in the 12–13 years group, showing that this age group was more confident than the other groups (Fig. 3.2A; continuous quadratic age: $\beta = .26$, $SE = .12$, $p = .029$, controlling for sex) despite performing at the same level on the perceptual judgements (Fig. 3.1C). Subsequent comparisons showed a significant difference in mean confidence between 8–9 years and 12–13 years ($t(69) = -2.23$, $d = .54$, $p = .029$) and between 12–13 years and 16–17 years ($t(75) = 2.08$, $d = .48$, $p = .041$) but not between 8–9 years and 16–17 years ($t(64) = -0.28$, $d = .07$, $p = .779$).

In addition, males were also more confident than females (Fig. 3.2B; $\beta = .25$, $SE = .09$, $p = .009$, controlling for age) despite matched performance ($t(105) = 0.30$, $d = .06$, $p = .764$).

Figure 3.2 **Higher mean confidence (metacognitive bias) in early adolescents and males**



Note. A) 12–13-year-olds show heightened mean confidence compared with other age groups. B) Male participants report heightened confidence compared to females. Error bars represent 95% confidence intervals. *p<.05 **<.01.

Adolescents have better metacognitive ability

Whilst metacognitive bias provides information about overall confidence, it does not provide any information about how well confidence ratings were calibrated to participants' actual performance. Metacognitive efficiency, on the other hand, measures how well participants' confidence ratings aligned with their performance.

I found an improvement in metacognitive efficiency in an adolescent-emergent pattern across age groups. Both adolescent groups (12–13-year-olds and 16–17-year-olds) had better metacognitive efficiency than the pre-adolescent group (8–9-year-olds; continuous adolescent-emergent: $\beta = .23$, $SE = .10$, $p = .023$; Fig. 3.3A). Subsequent comparisons showed the effect was primarily driven by improving metacognitive efficiency between 8–9 years and 16–17 years ($t(61) = -2.48$, $d = .63$, $p = .016$); 12–13-year-olds showed somewhat better metacognitive efficiency than 8–9-year-olds which narrowly missed statistical significance ($t(66) = -1.99$, $d = .50$, $p = .051$) and the adolescent groups showed very similar metacognitive efficiency (12–13-year-olds vs 16–17-year-olds: $t(75) = -0.26$, $d = .06$, $p = .795$). This means the confidence reports given by the adolescent groups were better calibrated to their actual performance than the confidence reports given by the pre-adolescent group.

Adolescents are less willing to take (misleading) advice from others

Next, I assessed how children and adolescents incorporate advice from others into their perceptual judgements. Using a post-decision paradigm (Meshi et al., 2012), I could assess how advice was weighted against participants' own initial performance and how this was related to their confidence.

To assess participants' overall propensity to follow advice, I first calculated the difference between the proportion of trials that participants changed their minds when the advisor disagreed vs when the advisor agreed with them (accounting for task-irrelevant switching behaviour). I found an (inverse) adolescent-emergent pattern, showing that the adolescent participants generally followed advice less than the youngest participants (Fig. 3.3B; continuous adolescent-emergent: $\beta = -.26$, $SE = .09$, $p = .005$), supporting the idea that adolescents are generally resistant to others' opinions. Subsequent comparisons showed propensity to follow advice was significantly higher in the 8–9-year-olds compared with 12–13-year-olds ($t(69) = 2.04$, $d = .48$, $p = .044$) and compared with 16–17-year-olds ($t(69) = 2.35$, $d = .57$, $p = .022$) but propensity to follow advice was not different between the two adolescent groups ($t(75) = 0.50$, $d = .12$, $p = .615$).

Given that advice is reliable in this task, following advice overall is sensible. However, a good decision maker will also take into account their own performance, weighing up the advice against their own decisions. Does this mean that the youngest participants, in contrast, are simply following advice blindly? To investigate resistance to false advice, I looked only at trials on which the advice was conflicting and calculated a difference score between the proportion of trials when participants were incorrect and followed the helpful advice (out of total number of trials participants were incorrect and received conflicting advice) and the proportion of trials when participants were correct but followed the misleading advice (out of total number of trials where participants were correct and received misleading advice).

A resistance score of zero means the participant did not discriminate between helpful and misleading advice when making their revised choice, a positive score means the participant followed helpful more than misleading advice and a negative score means the participant followed misleading more than helpful advice.

I found that the adolescent groups, compared with the youngest group, were more resistant to false advice and more willing to follow helpful advice (Fig. 3.3C; continuous adolescent-emergent: $\beta = .20$, $SE = .10$, $p = .037$). This shows that adolescents took their own performance into account when deciding whether to follow advice or not and because of this were better able to ignore misleading advice. By contrast, children tended to follow conflicting advice equally when it was helpful and when it was misleading. Subsequent comparisons showed the effect was mainly driven by a difference in resisting false advice between 8–9-year-olds and 12–13-year-olds ($t(69) = -2.03$, $d = .48$, $p = .046$) rather than between the other groups (8–9-year-olds vs 16–17-year-olds $t(64) = -1.55$, $d = .38$, $p = .127$; 12–13-year-olds vs 16–17-year-olds $t(75) = 0.68$, $d = .16$, $p = .496$). This suggests that adolescents do not simply ignore advice from others, but instead carefully examine their own knowledge and follow advice when they distrust their own decision.

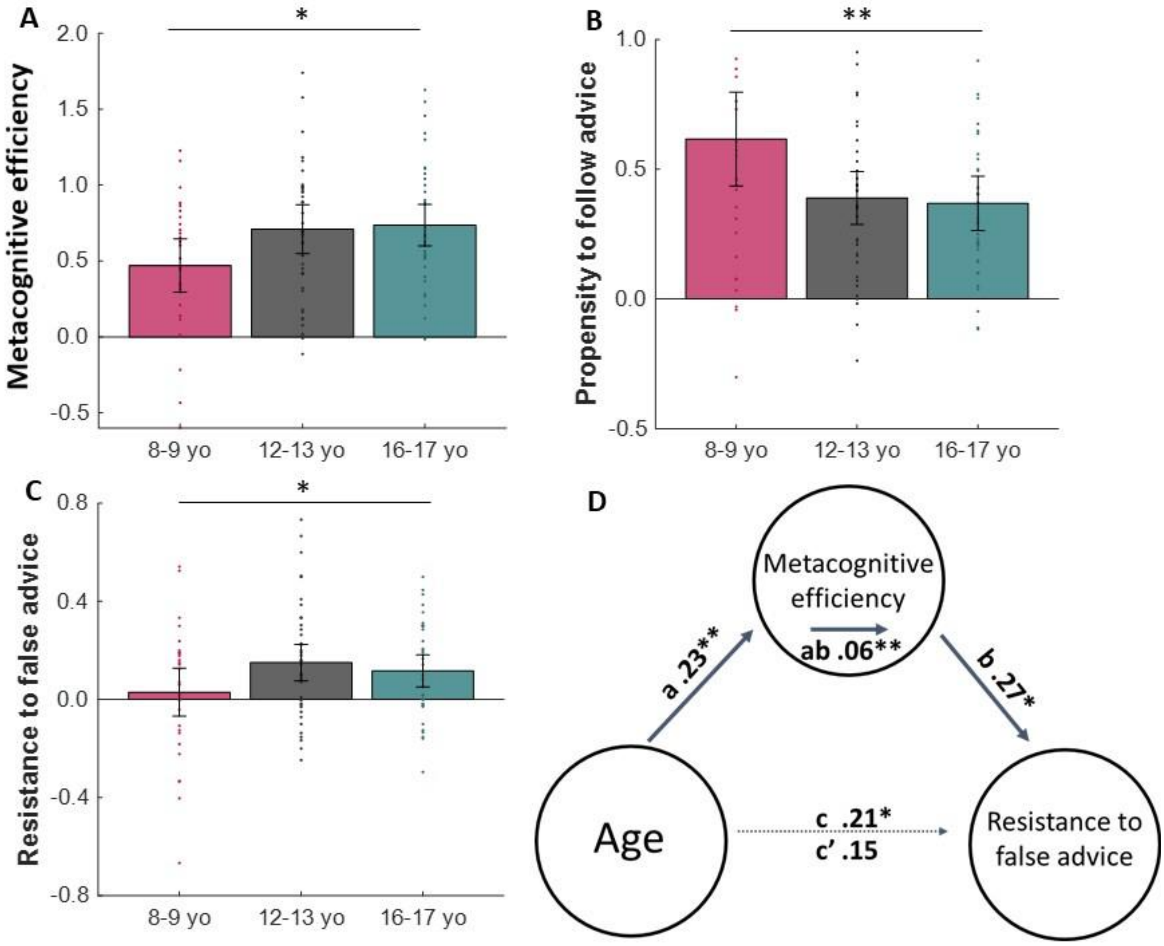
Better metacognitive ability promotes adolescents' ability to ignore misleading advice

So far, two parallel age-related effects have been observed. Adolescents had better metacognition i.e. were better able to take account of their own performance when deciding whether to follow advice. In addition, I showed that adolescents were better at arbitrating between their own decision and others' advice. I was thus interested in whether emerging metacognition was the driving factor behind improved advice taking. Simply speaking, the better our insight into our own performance, the more our confidence signals reflect our actual performance and the more we can utilize these confidence signals to resist misleading advice from others. To assess whether the adolescents' increased metacognitive efficiency allowed them to resist false advice but still take on helpful advice, I conducted a secondary mediation analysis assessing whether metacognition mediated the observed association between adolescent-emergent age and advice taking (see Statistical Analysis for details).

Our mediation analysis confirmed the significant associations between adolescent-emergent age and metacognitive efficiency (path *a*: mean $\beta = .23$, $SE = .09$, $z = 2.74$, $p = .006$) and between adolescent-emergent age and resistance to false advice (path *c*: mean $\beta = .21$, $SE = .10$, $z = 2.26$, $p = .024$). Moreover, I found a significant association between metacognitive efficiency and resistance to false advice (path *b*: mean $\beta = .27$, $SE = .11$, $z = 2.33$, $p = .020$). I found that the association between adolescent-emergent age and resistance to false advice was fully mediated by metacognitive efficiency (*ab*: mean $\beta = .06$, $SE = .04$, $z = 2.61$, $p = .009$), and the association between adolescent-emergent age and resistance to false advice was no longer significant when accounting for metacognitive efficiency (*c'*: mean $\beta = .15$, $SE = .09$, $z = 1.65$, $p = .098$). See Fig. 3.3D; details on path notation can be found in 'Statistical analysis'.

This pattern of results suggests that adolescents' ability to identify when they were correct and when they were incorrect allowed them to ignore advice more often when it was misleading, but incorporate advice when it was helpful. In contrast, children were less able to identify when they were correct or incorrect and so tended to follow conflicting advice independent of their own performance and whether the advice was helpful or misleading. This suggests that adolescents do not simply ignore advice from others but use their confidence signals to guide their advice taking behaviour.

Figure 3.3 **Metacognitive efficiency influences advice taking behaviour in adolescents**



Note. A) Both adolescent groups show greater metacognitive efficiency (meta-d'/d') than pre-adolescents, indicating that metacognition increased primarily between childhood and adolescence. B) In addition, significant developmental changes in advice following were found. The youngest were the most likely to follow advice compared to adolescent groups (calculated as the proportion of trials that participants followed, rather than ignored, advice when the advisor disagreed with their choice minus the proportion of trials that participants followed, rather than ignored, advice when the advisor agreed). C) Both adolescent groups were better able to resist false advice while still taking on helpful advice (calculated as the proportion of trials that participants were incorrect and switched to the advised correct choice rather than sticking with their incorrect choice minus the proportion of trials that participants were correct and switched to the advised incorrect choice rather than sticking with their correct choice). Children, however, were not able to discriminate helpful from misleading advice. D) The relationship between age (adolescent-emergent) and resistance to false advice was mediated by metacognitive efficiency. Mean beta values are shown, the *c* path represents the total effect of age on resistance to false advice and *c'* represents the effect of age on resistance to false advice when controlling for the mediator metacognitive efficiency. All graphs show raw values (before z-scoring). Error bars represent 95% confidence intervals. *p<.05 **p<.01.

Associations with mental health symptoms

In order to assess the associations between metacognition, advice-taking and mental health, I conducted linear regressions including either depressive or anxiety symptoms as the predictor variable of interest (correlation between depressive and anxiety symptoms: $r = .59$, $p < .001$).

I initially found that anxiety symptoms were correlated with d' (anxiety: $r = -.20$, $p = .041$; depression: $r = -.12$, $p = .223$). Therefore, I included d' as a control variable in all subsequent analyses, except for the model including metacognitive ratio (meta-d'/d') which already accounts for d' differences. I also included age (the term from the most parsimonious model) and sex as control variables.

In contrast to my predictions, I did not find any significant associations between the (meta)cognitive variables and mental health symptoms. There were no significant associations between depressive and anxiety symptoms and metacognitive bias (depression: $\beta = -.06$, $SE = .10$, $t = -.58$, $p = .562$; anxiety: $\beta = .03$, $SE = .10$, $t = .29$, $p = .775$), metacognitive efficiency (depression: $\beta = .02$, $SE = .02$, $t = .99$, $p = .323$; anxiety: $\beta = -.01$, $SE = .02$, $t = -.34$, $p = .732$), propensity to follow advice (depression: $\beta < .001$, $SE = .02$, $t = .01$, $p = .990$; anxiety: $\beta = .03$ $SE = .02$, $t = 1.18$, $p = .243$) or resistance to false advice (depression: $\beta = .01$, $SE = .02$, $t = .36$, $p = .718$; anxiety: $\beta < -.001$, $SE = .03$, $t = -.02$, $p = .980$). However, it should be noted that the study may not have been appropriately powered to detect such associations

Discussion

To understand when successful independent decision making emerges, I studied the development of metacognition and advice taking. I provide evidence that metacognitive efficiency matures from childhood to adolescence. Further, I show that this process supports more sensible advice-taking behaviour. In this way, adolescents were able to use their confidence signals successfully to reject misleading advice but take on helpful advice from others. Adolescents followed conflicting advice less often when they were correct, but took it when they were incorrect. This may be because adolescents' confidence signals better discriminated between correct and incorrect trials, so they were better able to use their confidence signals to determine when to follow advice, in other words: 'I know better! And I know I know better!'.

The development of metacognition, i.e. gaining better insight into our own behaviour, during adolescence may be an important driver for independent decision making. The results suggest that metacognitive efficiency and the ability to ignore false advice improve during the transition from childhood to adolescence. The best-fitting model described an adolescent-emergent trajectory of development, with major improvement in metacognitive ability and advice taking between participants in late childhood and early adolescence, but little change between early and mid-adolescence. This indicates that the transition from childhood into adolescence is a developmental period of substantial change in metacognitive and cognitive processes. This trajectory was well represented by the data even though I collected participant data in age groups rather than continuously sampling across childhood and adolescence (as previously e.g. Somerville et al., 2013). Importantly, all my continuous analyses are supported by subsequent between-groups tests showing the same effect.

This is the first investigation into the impact of metacognitive development across childhood and adolescence on advice-taking behaviour. I extend previous work on post-decision evidence integration, i.e. how individuals incorporate new information after a decision has been reached (Moran et al., 2015; Moreira et al., 2018; van den Berg et al., 2016; Yeung & Summerfield, 2012), to show that metacognitive efficiency at the initial decision underlies sensible integration of information post-decision (i.e. advice). My results show that when adolescents received conflicting advice, they changed their mind more when they were incorrect than when they were correct (i.e. they change their mind in a more sensible way than children).

This study aimed to address some of the methodological issues raised by previous research. I used a signal detection theoretic approach for the measurement of metacognition to be able to dissociate metacognitive bias from efficiency. Therefore, the finding that metacognitive efficiency improves across childhood into adolescence is independent of any developmental differences in overall confidence. I employed a perceptual decision-making paradigm with adaptive difficulty in order to fine-tune participants' level of accuracy. I also used metacognitive efficiency to measure how well participants discriminated correct from incorrect decisions while accounting for any remaining inter-individual performance differences. The current study offers a different angle to previous work in the development of metamemory. Recent work comparing different forms of metacognition and metamemory has suggested that metacognitive ability for perception is only weakly or not at all related to metamemory (Mazancieux et al., 2020; Rouault, McWilliams, et al., 2018). Moreover, patients with lesions to anterior prefrontal cortex show domain-specific impairment in perceptual but not memory-related metacognitive ability (Fleming et al., 2014). This was not the case for metacognitive biases in perceptual versus metamemory confidence, which are more closely related and may be domain-general (Mazancieux et al., 2020; Rouault, McWilliams, et al., 2018). This again highlights the importance of distinguishing these measures.

This research makes an important contribution to a wider literature on age of mental (decision-making) capacity, the age at which a person is able to make autonomous decisions, for example, about their own welfare (e.g. deciding between medications) or whether to enter into contractual agreements (e.g. buying property). There are multiple criteria that determine an individual's decision-making capacity (Department of Health et al., 2007). The current study may be particularly relevant for the criterion of 'use or weight', the ability to utilize multiple sources of information and weigh up their importance as part of the process of making a decision (Case, 2016; Grootens-Wiegers et al., 2017; Ruck Keene et al., 2019; van der Plas et al., 2019). Thus, a person's ability to weigh the advice of others against their own confidence in their decision is an important aspect of capacity-related decision making (van der Plas et al., 2019). I have shown here that adolescents' maturing metacognition contributes to their ability to weigh up advice from others in a more sensible way, not just following advice whenever someone disagrees. A further understanding of the mechanisms that drive advice taking behaviour and adolescent decision making will improve our understanding of the development of these important requirements for decision making capacity.

Interestingly, I additionally found that early adolescents (12–13-year-olds) showed heightened confidence compared with 8–9-year-olds and 16–17-year-olds (quadratic trajectory), in spite of the same level of performance across all age groups and in both sexes. This diverges from previous work suggesting that children are overconfident in judgements-of-learning (van Loon et al., 2017; Was & Al-Harthy, 2018). However, in studies with retrospective confidence judgements as in the current study, the results are mixed. Sometimes, children do not differ from early adolescents in their overall confidence judgements (7–9-year-olds were not more confident overall than 9–12-year-olds: Fandakova et al., 2017; no clear pattern of overconfidence with age across 7–16 years: Brackmann et al., 2019) or overall confidence appears to increase across adolescence (increase in overall confidence across 11–17 years; Weil et al., 2013). Relatively fewer studies have assessed retrospective trial-by-trial confidence in late childhood and adolescence and the existing studies cover different age groups, different experimental paradigms and different ways of calculating overall confidence. It would be interesting to synthesize results across different techniques to address these conflicting findings in further studies.

I also found that males were more confident than females. One previous study on metacognition during adolescence found sex-related differences in metacognition (Weil et al., 2013), but this was in metacognitive ability (measured by A_{roc}) rather than mean confidence (as reported here). Sex differences in metacognition have not been reported consistently in young children (Hembacher & Ghetti, 2013; Jaswal, 2010; Lyons & Ghetti, 2011; C. M. Roebers et al., 2004) or in adult studies with large samples (Rouault, Seow, et al., 2018). However, for some behaviours, sex differences may be heightened in adolescence (e.g. sex differences in risk-taking behaviours are smaller for adults than adolescents; Byrnes et al., 1999). Therefore, a sex-specific difference in confidence may be a unique feature of adolescence, but further investigations into sex differences across development are needed.

In this task I used a neutral ‘space advisor’ without providing detailed information about their identity (age, gender etc.). I chose a neutral space advisor to eliminate any biases in advice taking that might arise from providing details about the identity of the advisor. An important next step would be to contrast types of advice/advisors that are known to moderate the social influence of an agent (N. Hertz & Wiese, 2018, 2016; Lourenc et al., 2015; Toelch & Dolan, 2015). For example, the current study did not distinguish between normative vs informational influence, social vs non-social or peer vs adult advisors. Adolescents appear to be influenced by peers more than non-peers (e.g. adults or computers) in risk taking, moderating their behaviour simply in the presence of peers (Braams et al., 2019; Chein et al., 2011; Gardner & Steinberg, 2005; Reiter et al., 2019). Less is known about the effects of advice giving on adolescent behaviour. It may be the case, for example, that adolescents are less influenced by peers compared with adults when advice is informational (e.g. as in Lourenc et al., 2015) rather than normative (as in risk-taking studies). Thus, it would be interesting to investigate whether enhanced metacognitive insight in adolescents is equally as protective against the influence of false advice in different social contexts.

A further limitation of the study was the use of an advisor who performed at a similar level of accuracy to the participant. This meant that taking advice did not necessarily afford overall gains for the participants. Although, using an advisor at this performance level meant that I could assess an advanced strategy of advice-taking: young people should only take advice specifically on trials where they were incorrect. Nonetheless, it would be interesting for future research to vary the accuracy of the advisor to look at how this impacts advice-taking behavior in these age groups.

The observed advice-taking behaviour may have also reflected differing perceptions in the different age groups. Given the behaviour of participants in the current experiment, it may be that adolescents perceived the advisor as helpful but not all-knowing whereas the children may have interpreted their advice as highly reliable. Therefore, it may be interesting to explicitly assess the participants' beliefs about the identity of the advisor and the validity of their advice, to investigate developmental changes in beliefs about others and whether this impacts on advice taking behaviours.

Confidence-based measures, such as metacognitive bias and metacognitive efficiency, have been found to be associated with self-esteem and psychiatric symptom dimensions such as anxious-depression, compulsivity and intrusive thoughts (Moses-Payne et al., 2019; Rouault, Seow, et al., 2018). Further, post-decision evidence integration, a similar process to advice taking, has been shown to be associated with depressive symptoms (Moses-Payne et al., 2019). I thus explored these associations in the current study, investigating whether I would replicate a similar pattern of results in the current study. However, I did not find any significant associations between metacognitive and advice-taking behaviours and mental health measures. In contrast to previous research, I used separate scales rather than administering multiple questionnaires and employing item-wise factor analysis to create symptom dimensions, owing to the relatively low sample size. Therefore, in addition to the limited power to detect associations given my sample size, my analysis also had lower sensitivity to detect associations between depression and anxiety and, for example, overall confidence. This is because some of the items in the depression and anxiety scales used in the current study may be associated with a compulsivity dimension rather than an anxious-depression dimension, which have been reported to have opposing associations with decision confidence (Rouault, Seow, et al., 2018). Future work could test larger samples, assess a greater diversity of symptoms and conduct item-wise factor analysis, as implemented in previous studies, to further investigate whether developing populations show similar associations between metacognition and mental health symptoms.

To further this investigation, it would be particularly interesting to map the individual developmental trajectories of metacognition and advice-taking behaviour in longitudinal studies. Since adolescence is a period of heightened risk for the onset of mental health conditions (Kessler, Angermeyer, et al., 2007; Solmi et al., 2022), it would be interesting to investigate how trajectories of metacognitive development are associated with mental health symptom onset longitudinally. Longitudinal studies could also help to overcome some of the caveats that arise in mediation analysis of cross-sectional data (Lindenberger et al., 2011) and replication of the results reported here in an independent sample is important, considering that often very large samples are needed to detect mediation effects in psychology (Fritz & MacKinnon, 2007; Schoemann et al., 2017).

The transition from childhood to adolescence is associated with major physical and psychological changes (S. J. Blakemore et al., 2010). Adolescents may be particularly driven to seek independence and gain more responsibility (Koepke & Denissen, 2012a; Sebastian et al., 2008b). In this study, I have shown that the ability to accurately introspect about our own behaviour improves from childhood to adolescence. Further, I showed that adolescents harness this emerging ability to know when to take advice from others, and thus are able to take on helpful advice but ignore misleading advice. As Socrates implied, teenagers can sometimes appear ignorant towards others' advice. However, I find that teenagers may actually be making quite sensible decisions to ignore the advice of others when they know that they are correct. Metacognition may thus be a driving force, supporting adolescent decision making and the transition towards full independence.

The current chapter has investigated self-judgements about decisions. In the next chapter I consider how motivation to reduce uncertainty in the self-concept may impact adolescents' self-referential thinking. In particular, I consider how adolescents make self-judgements about their traits. The rapid development of metacognitive ability in early adolescence shown here, meaning young people become more realistic about the quality of their decisions, combined with the reduction in confidence in choices from early to late teenage years could encourage young people to become more self-critical and willing to make negative self-judgements. I will also explore whether there is evidence that early adolescents' (assumed) motivation to gather information about the self is reflected in their memory for self-referent stimuli.

Chapter 4

Age-related changes in the impact of valence on self-referential processing

Part of this chapter has been published as:

Moses-Payne, M. E., Chierchia, G., & Blakemore, S. J. (2022). Age-related changes in the impact of valence on self-referential processing in female adolescents and young adults. Cognitive Development, 61, 101128.

Abstract

Adolescence is a period of self-concept development and is often associated with increased self-consciousness and negative self-views. Here, I investigated how adolescents gather information about the self and whether the motivation to construct a sense of self is reflected in memory for self-referent stimuli. Females aged 11–30 years (N=210) completed two self-referential tasks. In an evaluative memory task, participants judged the descriptiveness of words for themselves or a familiar other and their recognition of these words was subsequently measured. In an associative-matching task, participants associated neutral shapes to either themselves or a familiar other and the accuracy of their matching judgements was measured. In the evaluative memory task, participants were more likely to remember self-judged than other-judged words and there was an age-related decrease in the size of this self-reference effect. Negative self-judgements showed a quadratic association with age, peaking around age 19. Participants were more likely to remember positive than negative words and there was an age-related increase in the magnitude of this positivity bias. In the neutral shapes task, there were no age-related changes in the self-reference effect. Overall, adolescent girls showed enhanced processing of self-relevant stimuli when it could be used to inform their self-concept and especially when it was negative.

Introduction

Adolescence begins with the onset of puberty and ends with the assumption of a stable, adult role (S.-J. Blakemore & Mills, 2014b; Patton et al., 2016b). By this definition, adolescence is a period during which individuals construct an autonomous sense of self (Koepke & Denissen, 2012b). It has been proposed that, compared with other ages, adolescents are more aware of and concerned with their self-concept (Brown, 2013; Elkind & Bowen, 1979; Erikson, 1968; Sebastian et al., 2008a). In this chapter, I assessed whether self-concept construction during adolescence would be reflected in heightened self-referential processing.

To assess self-referential processing, I evaluated the ‘self-reference effect’ (SRE), whereby stimuli associated with the self are better perceived or remembered than stimuli associated with others. For example, participants correctly recognise more words that were previously judged as descriptive of the self, compared with words that were judged as descriptive of another person (e.g. Harry Potter) or for their semantic or perceptual features (Leshikar et al., 2015; Rogers et al., 1977b). In associative-matching paradigms, participants show an SRE even when simply instructed to associate one shape stimulus with themselves and another shape with another person (Sui et al., 2012b). In such a paradigms, participants are generally faster and more accurate at processing self-associated shapes compared with other-associated shapes (Sui et al., 2012b).

The SRE has been demonstrated in children as young as 5 years (Sui & Zhu, 2005b), in adolescents (Dégeilh et al., 2015a) and in adults (Conway, 2005; Johnson, 2002; Leshikar et al., 2015; Rogers, 1977; Rogers et al., 1977b; Sui et al., 2012b; Sui & Humphreys, 2015b; Symons & Johnson, 1997b). Previous work has suggested that the SRE shows an age-related increase (increased difference in recall memory between self- and other-judged words) from age 7 to 11 (Halpin et al., 1984b; Hammen & Zupan, 1984b; Ray et al., 2009b). However, little is known about the trajectory of the SRE between early adolescence and adulthood. Here, I hypothesised that younger adolescent girls would find self-relevant stimuli particularly salient as they seek to construct their self-concept, and therefore show a larger SRE than in adulthood when their self-concept becomes more certain.

Self-referential recognition memory paradigms employ word stimuli that are valenced (as opposed to associative-matching tasks that employ neutral shapes). This allows for a separate line of analysis on the impact of valence on self-referential processing. Valence may be a particularly important factor in adolescent self-referential processing, as previous evidence has suggested that adolescents may be more willing to endorse negative statements about themselves (van der Aar et al., 2018b). Indeed, negative self-judgements appear to increase during adolescence, peaking around ages 15–17 years, and then decrease in early adulthood (McArthur et al., 2019b; van der Cruijsen et al., 2018b).

Assessing memory might give new insights into the effects of valence on self-referential processing compared with simply asking participants to self-report the descriptiveness of words. Previous evidence suggests that adolescents show a negativity bias, recalling more negative than positive words (Bone et al., 2021) compared with children, who recall equal numbers of positive and negative words (Quas et al., 2016). However, this difference depends on the conditions under which stimuli are encoded and retrieved, for example, whether the study employs a free recall or recognition memory test (Neshat-Doost et al., 1998b). In adults, some studies report a similar memory advantage for both positive or negative words compared with neutral words (in recognition memory: Adelman & Estes, 2013) whereas others report a memory advantage exclusively for negative (in recognition memory: Inaba et al., 2005;

Santaniello et al., 2018) or even positive words (in free recall: Herbert et al., 2008; and recognition memory: Lee & Potter, 2020). Less is known about valence effects on memory performance when stimuli are encoded in a self-referential condition and there has been little research addressing age-related change in self-referential memory valence effects (Kauschke et al., 2019).

Adolescence is associated with heightened self-consciousness and propensity to social anxiety (Beesdo et al., 2009; Beesdo-Baum & Knappe, 2012; Caouette & Guyer, 2014; Elkind & Bowen, 1979; Rankin et al., 2004; Somerville et al., 2013b). Self-consciousness refers to the disposition to attend to the self, self-focussed attention or an awareness of self-referent information (Fenigstein et al., 1975; Mor et al., 2010; Wu & Watkins, 2006). Therefore, if the SRE reflects attention to self-relevant stimuli, one would expect this to be associated with heightened self-consciousness. Social anxiety typically refers to a sensitivity to negative evaluations from others (Beesdo et al., 2009). Individuals use evaluations from others to inform their sense of self (Gallagher, 2000). Adolescents have been shown to be particularly sensitive to others' evaluations of them (Brown, 2013), and may be more likely than other ages to integrate others' views into their own self-concept (Pfeifer et al., 2009b). Here, I sought to investigate how self-consciousness and social anxiety influence the development of adolescents' self-referential processing as they emerge into adulthood.

Typically, adolescent girls self-report heightened self-consciousness (Rankin et al., 2004; F. R. Rosenberg & Simmons, 1975), greater propensity for social anxiety (Beesdo et al., 2009) and lower self-esteem (Quatman & Watson, 2001) than do adolescent boys. However, when measuring self-concept development (via competency ratings, trait descriptor ratings or in self-reference memory tasks), gender differences are not consistently reported and seem to depend on domain. For example, previous work has shown that boys' beliefs about their maths and language or arts competencies decreased more rapidly than girls' between ages 6 and 18 years (Jacobs et al., 2002). This was not the case for sports, where boys maintained higher competency beliefs than girls over time (Jacobs et al., 2002). More recently, McArthur et al. (2019) reported no gender difference in the trajectory of positive and negative self-schema (proportion of words both judged as descriptive and subsequently remembered, out of all positive or negative words judged) across age but showed that at age 13, on average, girls reported higher levels of positive self-schema than boys. However, in many previous studies using self-judgements, gender differences in self-referential processing were not investigated (Pfeifer et al., 2007, 2009b, 2013; van der Aar et al., 2018b; van der Cruijsen et al., 2018b). Here, I recruited only female participants because of their heightened self-consciousness and propensity to social anxiety (Beesdo et al., 2009; Rankin et al., 2004; F. R. Rosenberg & Simmons, 1975).

Overall, I aimed to assess how female adolescents and young adults might build upon their self-concept by prioritising self-relevant information (the self-reference effect). To do this, I measured self-referential processing, and the impact of valence on self-referential processing, in female participants aged 11–30. I employed two tasks: a recognition memory (words) task and an associative-matching (shapes) task, to contrast self-referential processing of stimuli that are evaluative (words task) versus neutral (shapes task). I measured self-consciousness and social anxiety using a self-report scale (Takishima-Lacasa et al., 2014) in order to assess the relationship between these measures and self-referential processing.

I hypothesised that the youngest participants would be most motivated to develop their self-concept and would find self-relevant stimuli most salient. Therefore, I predicted that the youngest participants would show the largest SRE in both the evaluative and neutral tasks (i.e. a larger difference in recognition of self-judged compared with other-judged words and a larger difference in speed and accuracy of judgements for self-associated shapes compared with other-associated shapes). I predicted that the SRE would show an age-related decrease as participants emerge into adulthood and their self-concept becomes more stable (Prediction 1). Based on previous literature, I predicted that negative self-judgements would increase across the adolescent years and decrease into adulthood (Prediction 2) and that memory for self-judged negative words would follow the same pattern with age (Prediction 3). I also tested whether heightened concern with others' opinions (measured by self-report public self-consciousness and social anxiety) was positively associated with increased negative self-judgements (Prediction 4) and whether heightened self-reflectiveness (measured by self-report private self-consciousness) was associated with an increased self-reference effect (Prediction 5).

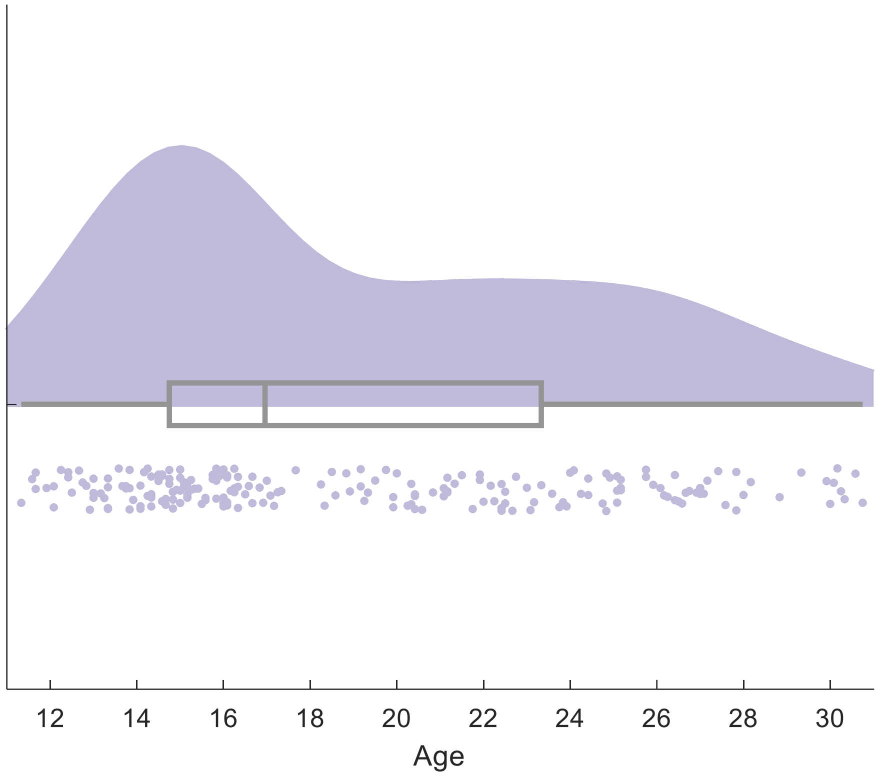
Methods

Participants and recruitment

I recruited 210 female participants aged 11.33–30.75 years (mean: 19.17, SD: 5.29; see Fig. 4.1). The lower age bound was chosen in order to capture the start of adolescence. The upper age bound was chosen so as to capture the end of adolescence (defined as mid-20s; (Sawyer et al., 2018b) and emerging adulthood. I expected that the development of most cognitive processes would have stabilised by age 30 (Becht et al., 2021a; Craik & Bialystok, 2006; Mills et al., 2016). Females only were recruited so that gender differences would not have to be accounted for and because of their reported heightened self-consciousness and vulnerability to social anxiety (Beesdo et al., 2009; Rankin et al., 2004). Participants were recruited from local secondary schools or university subject databases and paid £10 for their participation. Parents provided informed consent for participants under the age of 18. Participants over 18 provided informed consent themselves. Individuals with diagnosed developmental conditions, including dyslexia, dyscalculia and autism spectrum conditions were excluded from the study. All participants reported normal or corrected-to-normal vision. The study was approved by UCL Research Ethics Committee (Project ID: 3453/001).

Sixty-seven participants (~32%) were White-British, 33 (~16%) were Indian, 25 (~12%) were Chinese, 23 (~11%) were White-Other, 22 (~10%) were Asian-Other, 21 (~10%) were mixed, 13 (~6%) were Black-British or Black-African, four (~2%) were Bangladeshi and two (~1%) reported other ethnicities. All participants were fluent in English. One hundred and fifty-eight participants reported English as their first language, with three participants listing English alongside another language and 49 participants reported a first language other than English.

Figure 4.1 **Distribution of sample across age**



Note. Participants were aged 11.33–30.75. Box and whisker plot in grey shows min and max (ends of whiskers), lower quartile and upper quartile (ends of box) and median (line through box) of age. Dots represent individual participants and shaded area represents probability density.

Self-referential processing tasks

Participants completed a recognition memory (words) task and an associative-matching (shapes) task. In both tasks, participants were asked about stimuli that referred to the participants themselves or another person. Participants chose a female ‘familiar other’ whom they did not know personally (e.g. celebrity or fictional character). Once chosen, participants were asked to make a one-off rating of their familiarity with the chosen other on a scale from 0 “Not familiar at all” to 10 “Very familiar”, and their likeability from 0 “Don’t like her at all” to 10 “Like her very much”. This was done in order to ensure that participants across age chose to judge words in relation to people they were similarly familiar with and found similarly likeable, and could be used as a covariate in the case that age-related differences were found.

Recognition memory (words) task. The words task consisted of two stages – encoding and retrieval.

Encoding. During encoding, participants were asked to judge how well different words described themselves (‘Does this word describe you?’) or their chosen familiar other (‘Does this word describe [e.g. Hermione Granger]?’). Participants viewed the cue for 1000 ms followed by the person-descriptive word for 1000 ms. Participants judged the descriptiveness of the word on a 11-point scale from 0 (‘Does not describe me/her at all’) to 10 (‘Totally describes me/her’). The slider handle remained hidden until the participant’s first click (to avoid anchoring effects) and participants were given 7000 ms to make their rating.

Words were selected from Anderson H (1968) and Kirby & Gardner (1972) and were judged, prior to the study, by two adolescents aged 11 and 13 to ensure the youngest participants in the study would be able to comprehend the words. Post-hoc checks using age of acquisition data (Brysbaert & Biemiller, 2017; data available for 108/128 words) showed that the mean age of acquisition for the word stimuli was 4.32 years old and none of the words had an age of acquisition later than 10 years old.

Participants judged a total of 64 words based on how well they described themselves (32 words: 18 positive, 14 negative) or their chosen familiar other (32 words: 18 positive, 14 negative). Words were coded as positive or negative using a median split on the likeability or social desirability ratings (taken from Anderson, 1968 and Kirby and Gardner, 1972 respectively).

Retrieval. During retrieval, participants were given a surprise recognition test for words presented in the encoding stage. Participants were tested on all 64 target words, seen in the encoding stage, alongside 64 distractor words (with the same ratio of positive and negative words). Thus, participants made recognition judgements for 128 words in total. Participants viewed the recognition question ('Have you seen this word before?') for 1000 ms followed by the word for 1000 ms and pressed the left or right arrow to indicate their response. Recognition judgements were self-paced, both the question and word remained on the screen during the judgement.

Allocation of words. The allocation of words to either target or distractor was pseudo-randomised across participants. To this end, the 128 words were split into eight lists of 16 words (see Table 4.1, each column corresponds to a list of words). For each participant, an algorithm selected at random four lists to be displayed during the encoding stage (two lists for self-judgements, two lists for other-judgements; target words). All eight lists were displayed at the retrieval stage (with the four unselected lists acting as distracter words). This was done to ensure all participants judged the same number of positive and negative words in each condition (self- and other-judged) and in both stages of the task. In both stages, words were displayed sequentially in a random order.

Associative-matching (shapes) task. In the shapes task, participants were instructed that one shape (either a circle or square, counterbalanced between participants) would represent them (self condition) and the other shape would represent their chosen familiar other (other condition).

On each trial, participants were presented with a central fixation cross for 500 ms, followed by the shape-label pair for 100 ms. The shape, either a circle or square, was presented above the fixation cross and the label, either ‘you’ or ‘her’ (selected to match number of letters and stimulus size), was presented underneath the fixation cross. Participants indicated (within 2000 ms) whether the shape and label were a match or not (i.e. if the square represents the self then when square is presented with ‘you’, the correct response is yes) by pressing the left or right arrow key (counterbalanced). Feedback was given through either a smiley or sad face with ‘correct’ or ‘incorrect’ below for 500 ms. Participants were instructed to respond as quickly and as accurately as possible.

The task procedure was adapted from Sui et al. (2012). The stimuli were optimised for a standard computer monitor size of 22 inches, although precise visual angles could not be replicated as participants completed the task on a variety of computer screens (as I tested across three different schools in computer classrooms and in testing cubicles on university campus).

Self-consciousness questionnaire

Participants were asked to complete the Revised Self-consciousness Scale for Children (Takishima-Lacasa et al., 2014). They were asked to indicate their agreement with 29 statements on a Likert scale from 1 (‘strongly disagree’) to 5 (‘strongly agree’). These items were analysed using confirmatory factor analysis to extract three factors (replicated from Takishima-Lacasa et al., 2014): public self-consciousness (representing style and appearance consciousness), private self-consciousness (representing self-reflectiveness and internal state awareness) and social anxiety (see ‘Statistical analysis’ for more detail).

The R-SCS-C showed good internal reliability in the dataset (Cronbach’s alpha: .78, 95% CI [.77 .79]). Takishima-Lacasa et al. (2014) examined the validity of the scale, in a sample of 7–18-year-olds, through correlations with the Imaginary Audience Scale (IAS; Elkind & Bowen, 1979), the Revised Child Anxiety and Depression Scales (RCADS; Chorpita et al., 2000) and the Positive and Negative Affect Schedule for Children (PANAS-C, Laurent et al., 1999). The R-SCS-C social anxiety and public self-consciousness subscales were significantly correlated with both subscales of the IAS (transient and abiding self), subscales of the RCADS (social phobia, major depression) and both subscales of the PANAS-C (positive and negative affect). Private self-consciousness was significantly correlated with both subscales of the PANAS-C and the RCADS social phobia and major depression subscale (Takishima-Lacasa et al., 2014).

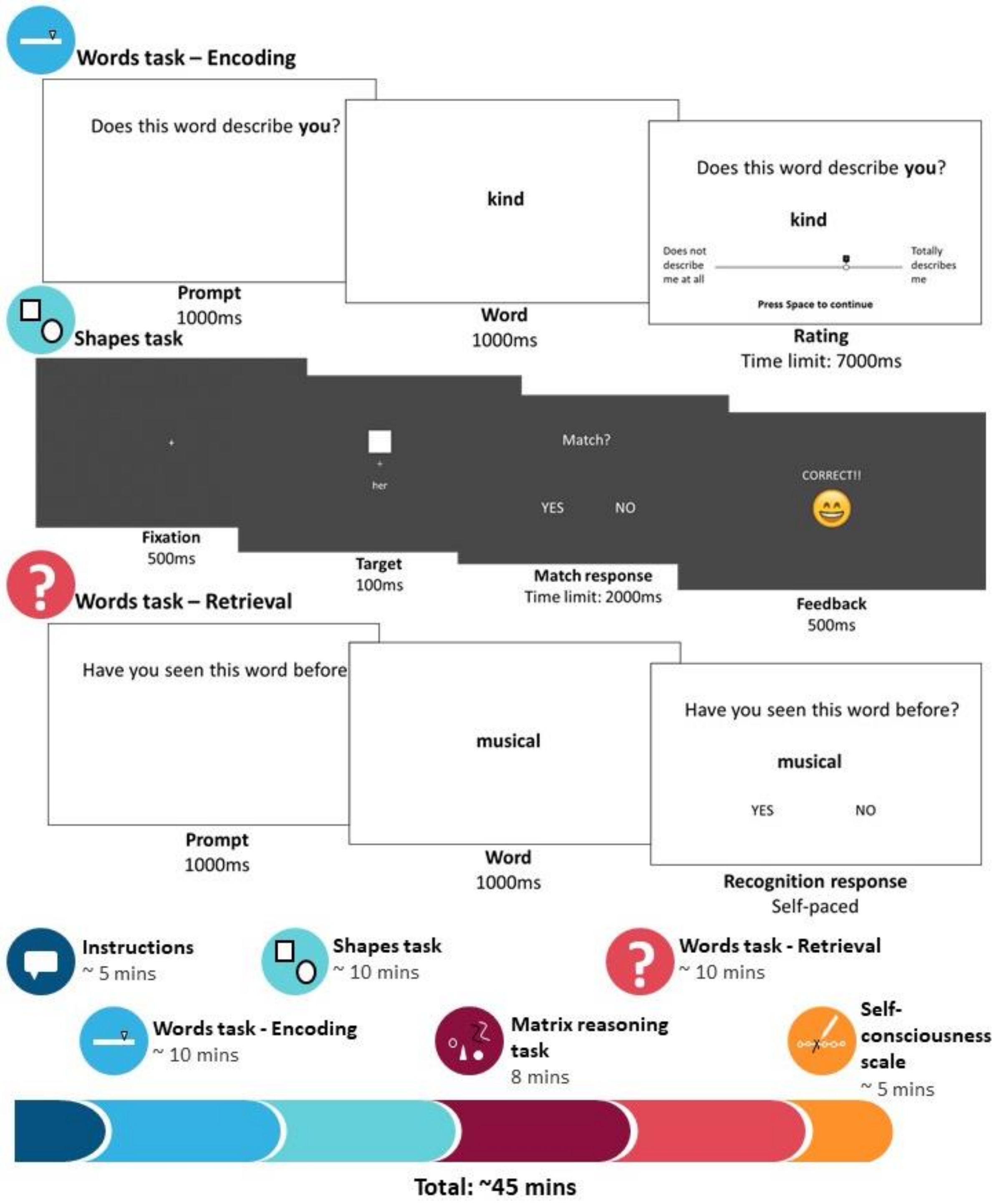
Matrix Reasoning

I included a measure of matrix reasoning as a covariate (in line with previous work, Chierchia et al., 2020a) to ensure age-related differences in self-referential processing were not due to differences in non-verbal reasoning ability. To measure non-verbal reasoning ability, the Matrix Reasoning Task (MaRs-IB; Chierchia et al., 2019) was used. In this task, participants are asked to complete an incomplete matrix containing abstract shapes, by choosing the missing shape from four options. The percentage of correct answers was calculated as a measure of non-verbal reasoning ability for each participant and this measure was included as a covariate in all analyses. The advantage of the MaRs-IB task over other non-verbal reasoning tasks is that it is online, open access and short (8 minutes).

Procedure

Participants were tested in groups (testing group size varied from two to 19 and was included as a covariate in all analyses) in a classroom setting (under-18s) or in study cubicles (over-18s). Participants were given verbal instructions at the beginning of the experiment. Participants then entered their age and their chosen 'familiar other' person. Participants completed the encoding stage of the recognition memory words task, followed by the associative-matching shapes task and the non-verbal reasoning task (MaRs-IB; which both also acted as distractor tasks for the words task). After this, participants were given the surprise recognition test in the words task (retrieval stage). All tasks were created and hosted on Gorilla.sc. Finally, participants completed the self-consciousness scale (Takishima-Lacasa et al., 2014) on paper. In total, participants spent approximately 45 mins doing the experiment (See Fig. 4.2).

Figure 4.2 **Procedures and timings**



Note. Words task – Encoding: Participants saw a prompt 'Does this word describe you/[chosen other]?' followed by the target word (e.g. kind) and then submitted their rating on a slider from 0 'Does not describe me/her at all' to 10 'Totally describes me/her'. Shapes task: Participants saw a fixation cross, followed by the target stimulus (shape-label pair, any combination of circle/square-you/her), and responded to the prompt ‘Match?’ by pressing left or right arrow key for ‘yes’ or ‘no’ (counterbalanced). Participants were given feedback in the form of a smiley or sad face. Words task – Retrieval: Participants saw a prompt ‘Have you seen this word before?’, followed by the target word (e.g. ‘musical’) and responded by pressing the left or right arrow key for ‘yes’ or ‘no’ (counterbalanced). Timeline of procedure (bottom panel): Participants received both verbal and written instructions. They then completed descriptiveness ratings, the shapes task and matrix reasoning task, the surprise recognition memory test and finally the self-consciousness scale.

Statistical analysis

For details of model implementation and comparison, see Statistical Methods.

In the words task, I conducted four separate models for the four dependent variables: descriptiveness ratings (at encoding; see Table 4.2, Model 1), recognition accuracy at retrieval (Model 2) and reaction times (RTs) at encoding (Model 3) and RTs at retrieval (Model 4). I investigated the relationship between these four dependent variables and three independent variables: condition (self- vs other-judged) and word valence (positive vs negative) as within-subject factors, and age, as a between-subjects factor. I also analysed whether descriptiveness ratings predicted recognition accuracy, by including descriptiveness ratings as an additional independent variable (Model 5). Recognition accuracy was a binary variable (coded as 1 for correct and 0 for incorrect) and was assessed for target trials only (but false alarm rate was included as a covariate).

In the shapes task, I conducted two separate models for the two dependent variables: matching accuracy (Model 6) and RTs (Model 7). I investigated the relationship between these dependent variables (matching accuracy and RTs) and two independent variables: condition (self vs other) as a within-subjects factor, and age as a between-subjects factor. Accuracy was a binary variable (coded as 1 for correct, 0 for incorrect) and was assessed for matching judgements only (as in Sui et al., 2012).

For both tasks, RTs were taken from correct trials only and were log-transformed to better approximate a normal distribution. RTs less than 250 ms were excluded. I included matrix reasoning scores (from MaRs-iB) and testing group size (number of participants in the same testing room) as covariates in all analyses.

Model comparison results showed that for descriptiveness ratings, the third-degree polynomial (including linear, quadratic and cubic components of age) was not a significantly better fit than the second-degree polynomial (linear and quadratic components of age; $\chi^2(4) = 7.96$, $p = .093$) but the second-degree polynomial was a significantly better fit than the first-degree polynomial ($\chi^2(4) = 13.66$, $p = .008$). For recognition accuracy, the second-degree polynomial was the most parsimonious and fit better than a model with the first-degree polynomial (second-degree versus first-degree: $\chi^2(4) = 13.66$, $p = .008$). For descriptiveness ratings RT, the second-degree polynomial fit significantly better than the first-degree polynomial ($\chi^2(4) = 18.76$, $p < .001$). For recognition RTs, the third-degree polynomial fit was not better than the second-degree polynomial ($\chi^2(4) = 1.10$, $p = .893$) and the second-degree polynomial was not better than the first-degree ($\chi^2(4) = 5.34$, $p = .254$). For the shapes task accuracy, the second-degree polynomial fit better than the first-degree ($\chi^2(4) = 11.48$, $p = .003$) and for matching RT the third- was not better than second-degree but the second-degree polynomial was a better fit than first-degree (third- versus second-degree: $\chi^2(4) = 4.72$, $p = .094$; second- versus first-degree: $\chi^2(4) = 32.65$, $p < .001$).

In summary, the model fitting comparison procedure thus suggested that the second-degree polynomial function of age (i.e. including linear and quadratic functions of age) provided the most parsimonious fit; except for word recognition RTs, where a linear model was the most parsimonious fit.

Table 4.1 **Model comparison of different forms of age for each task outcome.**

	Akaike Information Criterion (AIC)					
	Words task				Shapes task	
Form of age	*Descriptiveness ratings*	*Recognition accuracy*	*Descriptiveness ratings (RT)*	*Recognition (RT)*	*Matching Accuracy*	*Matching RT*
Age	63737.35	13138.47	16322.60	21409.57	8648.97	9090.90
e^{Age}	64009.59	13145.95	16599.83	21679.06	8664.68	9230.04
log(Age)	63766.48	13138.33	16347.15	21436.46	8646.34	9100.54
Age^{-1}	63744.68	13138.02	16320.89	21413.59	8643.96	9084.27
Age^{2}	63817.08	13138.50	16406.45	21488.84	8652.15	9134.42
Age^{3}	63843.93	13138.51	16436.55	*21516.23*	8655.11	9150.51
$Age+Age^{2}$	*63713.19*	***13122.22***	***16307.17***	*21405.31*	***8641.49***	*9058.68*
$Age+Age^{2}+Age^{3}$	**63694.73**	13138.02	16308.03	**21405.26**	8643.81	**9054.15**

Note. Lower AIC values indicate a more parsimoniously fitting model. Bold values indicate the lowest AIC for different model outcomes; italics indicate the selected model after nested model comparison using ANOVA.

As fixed effects, I investigated the interaction between, for the words task, the three independent variables (age, condition and target valence) and, for the shapes task, the two independent variables (age and condition), and all lower-level interactions and main effects. As random intercepts, I used participant-level IDs. I simplified the random slopes structure by removing the interaction between random slopes for condition and valence (as suggested by Barr, 2013; See Statistical Methods), allowing the model to converge (see Table 4.2, Models 3-4, 8-10).

Table 4.2 **Model equations.**

	Dependent variable	**Fixed Effects**	**Random Effects**
	Words task		
	Descriptiveness ratings and recognition accuracy		
Model 1	Descriptiveness ratings (1-10)	Age * Condition * Valence + MaRs-IB + Testing group size	Condition * Valence
Model 2	Recognition accuracy (1/0)	Age * Condition * Valence + MaRs-IB + FA + Testing group size	Condition * Valence
Model 5	Recognition accuracy (1/0)	Age * Condition * Valence + MaRs-IB + FA + Rating + Testing group size	Condition * Valence
	RTs		
Model 3	RTs (log) at encoding	Age * Condition * Valence + MaRs-IB + Testing group size	Condition + Valence
Model 4	RTs (log) at retrieval	Age * Condition * Valence + MaRs-IB + Testing group size	Condition + Valence
	Relationship with self-consciousness scale		
Models 8–9: Social anxiety, public self-consciousness	Descriptiveness rating (1-10)	Questionnaire factor scores * Condition * Valence + MaRs-IB + Testing group size	Condition + Valence

Model 10: Private self-consciousness	Recognition accuracy (1/0)	Questionnaire factor scores * Condition * Valence + MaRs-IB + Testing group size	Condition + Valence
	Shapes task		
	Accuracy		
Model 6	Matching accuracy (1/0)	Age * Condition + MaRs-IB + Testing group size	Condition
	RTs		
Model 7	RTs (log)	Age * Condition + MaRs-IB + Testing group size	Condition

Note. All models used trial-level data. Each model includes the second-degree polynomial of age (i.e. including linear and quadratic functions of age). Condition is a binary variable describing whether stimuli (words and shapes) were self- or other-judged in the words task, and self- or other-associated in the shapes task. Valence is a binary variable describing whether words were positive or negative. MaRs-IB is the proportion correct on the Matrix Reasoning task, included as a covariate to control for age-related differences in reasoning. Testing group size denotes the number of participants in the same testing room. FA is individual level false alarm rate in the words task. * indicates interactions for individual terms and all lower-level interactions.

Self-consciousness questionnaire

Using confirmatory factor analysis, I obtained participant-level factor scores of a three-factor solution, as reported in Takishima-Lacasa et al. (2014). These three factors are social anxiety (example: ‘Large groups make me nervous’), public self-consciousness (example: ‘I often check the way I look’) and private self-consciousness (example: ‘I like to understand why I do things’). Confirmatory factor analysis was performed using R *lavaan* package. Although model test statistics did not reach the cut off for good fit (χ^2 (374) = 940.50, p < .001; CFI = .74; TLI = .71; RMSEA = .085), a three-factor model was a better fit than a single-factor model or any combination of factors to make a two-factor model according to both AIC and Bayesian Information Criteria (BIC; see Table 4.3). Modification indices were also inspected but did not indicate any modifications that would make a substantial difference to model fit (all values below 10).

Table 4.3 **Model comparison in self-consciousness scale confirmatory factor analysis.**

Model	AIC	BIC	Sample-size adjusted BIC
Three-factor (Takishima-Lacasa et al., 2014)	**17067.00**	**17271.17**	**17077.89**
One-factor	17942.83	18136.96	17953.18
Two-factor (public and social anxiety factors combined)	17451.11	17648.59	17461.64
Two-factor (public and private combined)	17566.72	17764.20	17577.25
Two-factor (private and social anxiety combined)	17461.83	17659.31	17472.37

Note. A three-factor model structure from Takishima-Lacasa et al., (2014), in bold, was the winning model with the lowest AIC, BIC and sample-size adjusted BIC.

Table 4.4 **Factor loadings for each self-consciousness scale questionnaire item.**

	Public	Private	Social Anxiety
I worry about the way I look	0.571		
I notice my inner feelings a lot		0.561	
Large groups make me nervous			0.622
I often check the way I look	0.715		
I know how my body reacts to certain feelings		0.402	
I know how my feelings affect how I act		0.399	
I feel scared when I have to talk in front of a group			0.758
I get embarrassed very easily			0.706
It is important for me to look good	0.768		
I am in touch with my feelings		0.668	
I spend a lot of time on my looks	0.697		
I try to understand what my feelings mean		0.781	
It takes me time to get over shyness in a new place			0.645
I care about how I look in pictures	0.547		
I care about the way other people think I look	0.629		
I can always tell when feelings are changing		0.513	
I like to understand why I do things		0.548	
I feel scared when I meet someone new			0.669
I’m worried about how I do things			0.452
I often ask other people how I look	0.532		
I pay attention to what is ‘in style’	0.481		
I am interested in my thoughts		0.555	
I don't like performing in front of other people			0.611
I pick my clothes out carefully	0.492		
One of last things I do before I leave the house is look in the mirror	0.571		
I know right away when I am feeling happy or sad		0.352	

I'm always trying to understand myself		0.735
I make sure I look right before I leave the house	0.595	
I usually know how I feel about things		0.441

I explored associations between factor scores and the task measures by including factor scores as dependent variables in the mixed-models (replacing age; see Table 4.2, Models 8-10).

Results

Familiarity and likeability of chosen other

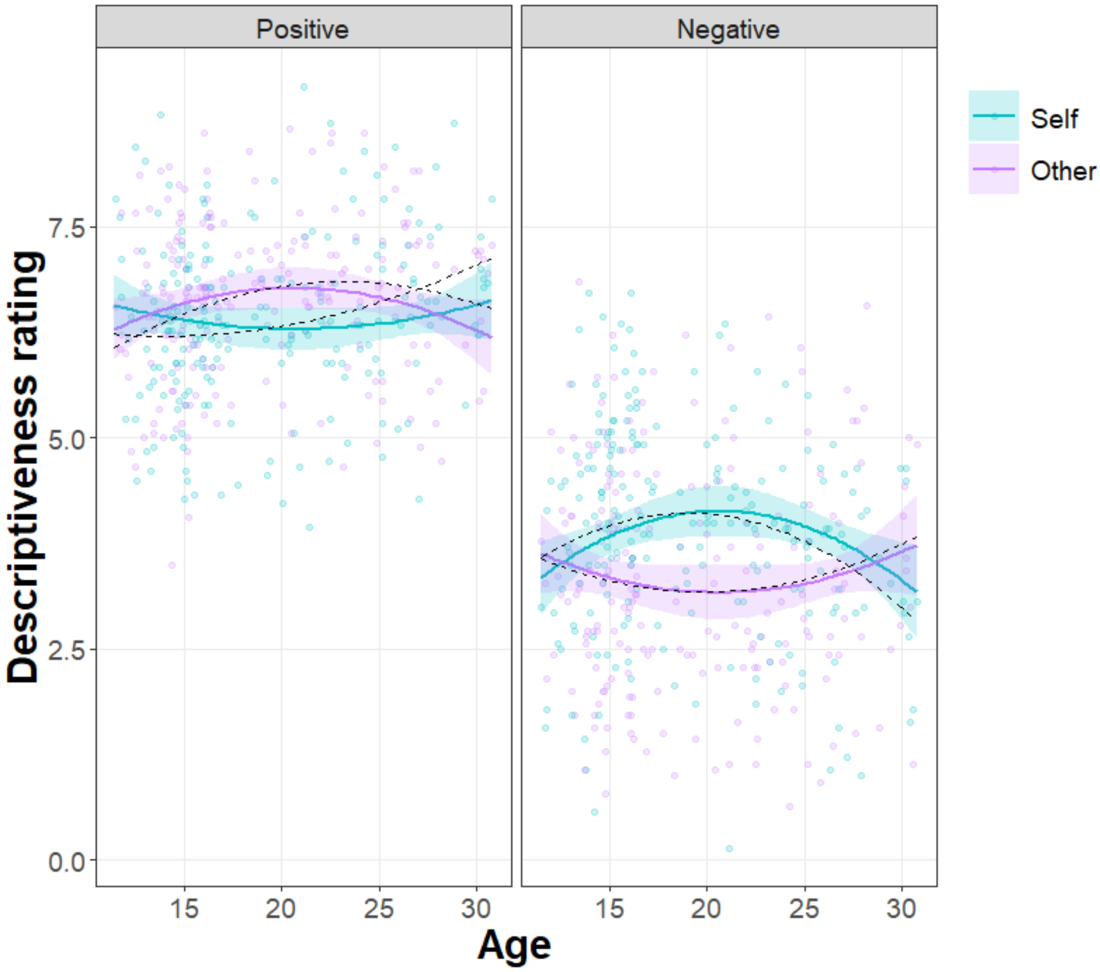
Participants tended to choose people with whom they were familiar (mean (SD) familiarity rating = 6.31 (2.26); max score 10) and who they liked (mean (SD) likeability rating = 8.21 (1.77); max score 10). Likeability and familiarity ratings were not correlated with participant age (likeability: r = -.101, p =.143; familiarity: r = -.079, p = .253). Participants chose fictional characters (107 participants) or public figures e.g. singers, actors, youtubers etc. (79 participants; 24 unidentifiable as only first name given).

Recognition memory (words) task

Encoding - Descriptiveness ratings. Participants rated positive words overall as more descriptive than negative words (main effect of valence: χ^2 (1) = 792.84, p < .001, $\text{contrast}_{\text{Pos-Neg}}$ = 2.90, SE = .1, p < .001). There was an interaction between age and valence (χ^2 = 5.86, p = .015), in that the tendency to rate positive words as descriptive showed an age-related linear increase ($\text{slope}_{\text{Pos}}$ = 22.23, SE = 7.0, p = .001) whereas the tendency to rate negative words as descriptive stayed relatively stable with age ($\text{slope}_{\text{Neg}}$ = -6.69, SE = 9.0, p = .458; $\text{contrast}_{\text{Pos–Neg}}$ = 28.90, SE = 11.9, p = .016).

There was a three-way interaction between the quadratic component of age, valence and condition (χ^2 (1) = 11.66, p = .001; Fig. 4.3). Inspection of model estimates revealed that there was an age-related increase in negative self-judgements between 11 to 19 years, which peaked at around 19 years, and was followed by an age-related decrease across the 20s. This was shown in the negative quadratic association (inverted U-shaped curve) between age and ratings of negative self-judged words (Prediction 2; $slope_{Self\ (Neg)}$ = -25.99, SE = 9.8, p = .008; Fig. 4.3 right panel). This was not the case for ratings of negative other-judged words ($slope_{Other\ (Neg)}$ = 15.40, SE = 10.7, p = .149; $contrast_{Self-Other\ (Neg)}$ = -41.39, SE = 12.1, p_{Bonf} = .001; Fig. 4.3 right panel). There was also a negative quadratic association (inverted U-shaped curve) between age and the tendency to rate positive words as more descriptive of the other (peaking at age 23.2) but not the self ($slope_{Other\ (Pos)}$ = -15.91, SE = 7.7, p = .038; $slope_{Self\ (Pos)}$ = 9.14, SE = 8.0, p = .254; $contrast_{Self-Other\ (Pos)}$ = 25.05, SE = 10.3, p_{Bonf} = .030; Fig. 4.3 left panel).

Figure 4.3 **Self- and other-judged descriptiveness ratings for positive versus negative words plotted against age in years**



Note. Participants rated words on a scale from 0–10. Solid coloured lines represent significant quadratic component of age, dotted black lines represent estimated fixed effects for the polynomial effect of age (ribbons: 95% confidence interval); data points are participants' mean descriptiveness ratings.

Encoding – Reaction times. Participants were faster at rating descriptiveness of words for the familiar other than for themselves (main effect of condition: $\chi^2(1) = 9.38$, $p = .002$; contrast$_{\text{Self-Other}} = .03$, SE = .01, $p = .002$) and positive compared with negative words (main effect of valence ($\chi^2(1) = 105.07$, $p < .001$; contrast$_{\text{Pos–Neg}} = -.08$, SE = .01, $p < .001$). There was a significant effect of both components of age (main effect of age: linear $\chi^2(1) = 5.31$, $p = .021$, β = -9.23, *SE* = 4.01, $p = .022$; main effect of age: quadratic $\chi^2(1) = 16.54$, $p < .001$, β = 11.62, *SE* = 2.86, $p < .001$), showing an age-related decrease in descriptiveness ratings RTs that plateaued around age 22.

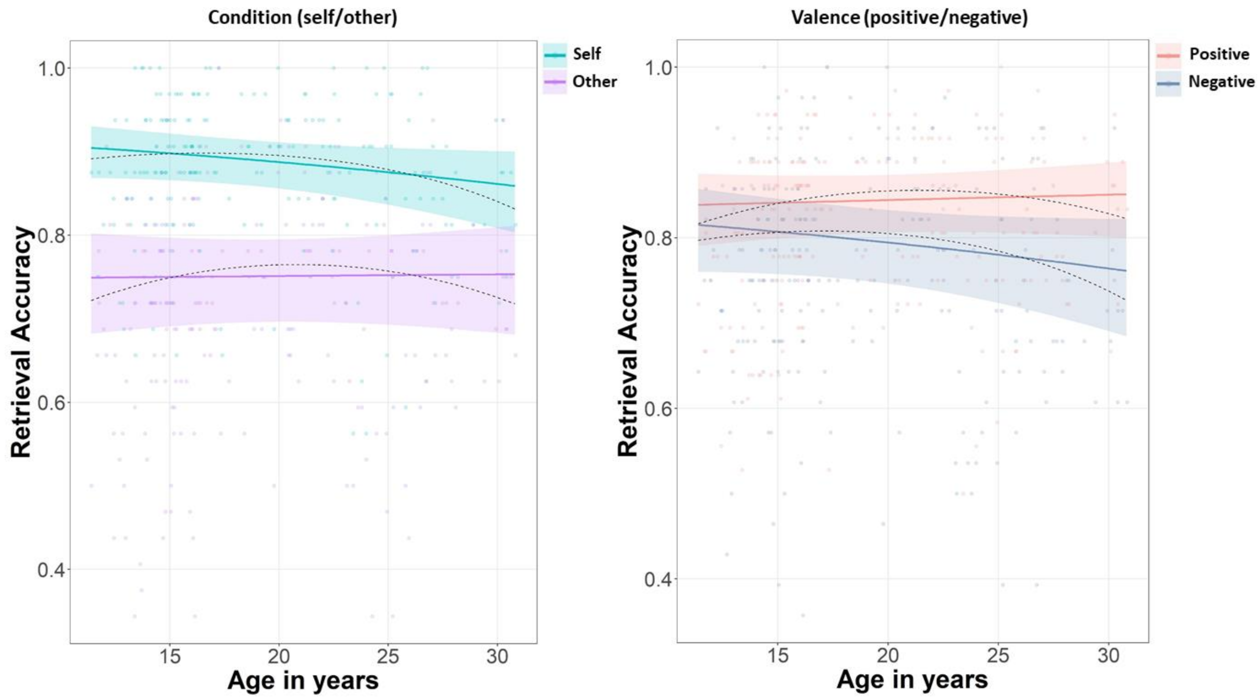
Retrieval - Recognition Accuracy. Memory performance overall remained stable across age (main effect of age: linear χ^2 (1) = .77, $p = .379$; quadratic χ^2 (1) = 1.92, $p = .166$).

There was a significant SRE overall, as on average participants correctly recognised more self-judged than other-judged words (main effect of condition, self vs other: χ^2 (1) = 328.86, $p < .001$; contrast$_{\text{Self – Other}} = 1.02$, *SE* = .1, $p < .001$). The size of the SRE reduced linearly with age (Prediction 1; interaction linear age and condition: χ^2 (1) = 4.29, $p = .038$; Fig. 4.4 left panel), such that memory for self-judged words decreased linearly and memory for other-judged words increased linearly across the age range (11-30 years; slope$_{\text{Self}} = -22.12$, *SE* = 14.3, $p = .122$; slope$_{\text{Other}} = .27$, *SE* = 12.8, $p = .983$; contrast$_{\text{Self-Other}} = -22.4$, *SE* = 10.8, $p = .038$).

There was a significant memory positivity bias overall, as on average participants correctly recognised more positive than negative words (main effect of valence: χ^2 (1) = 43.19, $p < .001$; contrast$_{\text{Pos – Neg}} = .35$, *SE* = .05, $p < .001$). This positivity bias in memory increased linearly with age (interaction age and valence: χ^2 (1) = 7.32, $p = .007$;

Fig. 4.4 right panel), such that memory for negative words decreased and memory for positive words increased across the age range (11- 30 years; $slope_{Pos}$ = 3.08, *SE* = 13.0, *p* = .813; $slope_{Neg}$ = -24.93, *SE* = 13.9, *p* = .073; $contrast_{Pos-Neg}$ = 28.0, *SE* = 10.4, *p* = .007).

Figure 4.4 **Recognition accuracy plotted against age in years**

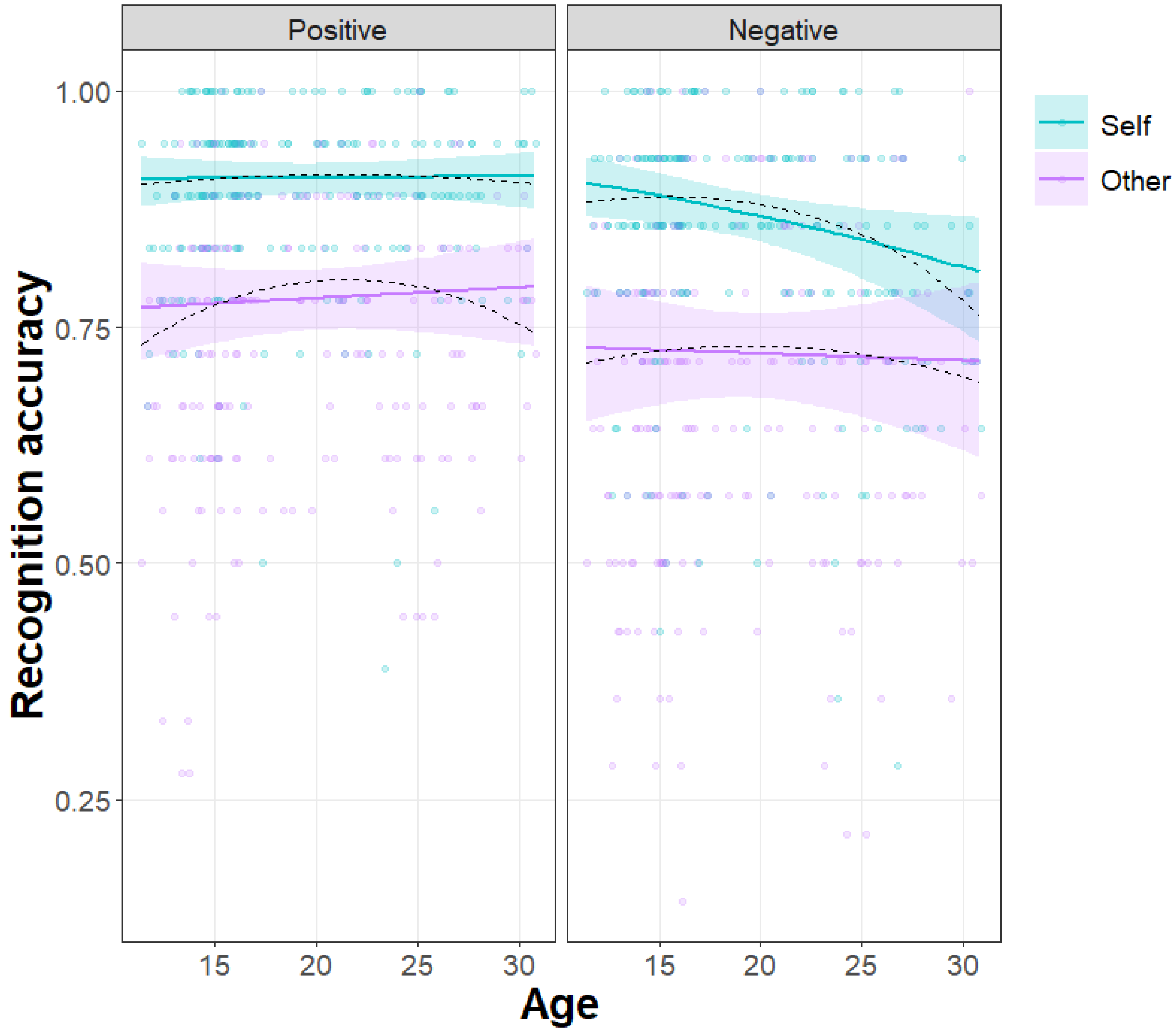


Note. Recognition accuracy plotted against age in years. Left panel: Recognition accuracy for self- and other-judged words against age (collapsed across positive and negative words). Right panel: Recognition accuracy for positive and negative words against age (collapsed across self- and other-judged). For both figures, solid lines represent the significant linear component of age; dotted lines represent the estimated fixed effects for the polynomial effect of age (ribbons: 95% confidence interval); data points are participants' proportion recognition accuracy.

Finally, recognition of self-judged negative words specifically appeared to decrease linearly across the age range (Fig. 4.5). Although the three-way interaction between the linear component of age, valence and condition narrowly missed significance (Prediction 3; χ^2 (1) = 3.63, p = .057), I conducted post-hoc exploratory comparisons to compare slopes for negative versus positive self- and other-judged words. For negative words, memory for self-judged words decreased linearly with age but memory for other-judged words stayed relatively stable ($\text{slope}_{\text{Self (Neg)}}$ = -44.67, SE = 16.3, p = .006; $\text{slope}_{\text{Other (Neg)}}$ = -5.20, SE = 14.6, p = .723; $\text{contrast}_{\text{Self–Other (Neg)}}$ = -39.47, SE = 13.7, p_{Bonf} = .008; Fig. 4.5 right panel). In contrast, there was no age-related change in memory for either self-judged or other-judged positive words ($\text{slope}_{\text{Self (Pos)}}$ = .42, SE = 16.3, p = .979; $\text{slope}_{\text{Other (Pos)}}$ = 5.73, SE = 13.3, p = .667; $\text{contrast}_{\text{Self–Other (Pos)}}$ = -5.32, SE = 14.4, p_{Bonf} = 1; Fig. 4.5 left panel). However, since the three-way interaction was non-significant (p = .057) these results should be interpreted with caution.

When including descriptiveness ratings as an additional predictor in the mixed-effects model, descriptiveness ratings significantly predicted recognition accuracy (χ^2 (1) = 138.82, p = .001), indicating that words rated as more descriptive by participants were more likely to be remembered across all ages. All effects reported above remained significant in this model, except for the main effect of valence (main effects: condition χ^2 (1) = 317.26, p < .001; valence χ^2 (1) = 1.09, p = .297; interactions: age-by-condition χ^2 (1) = 3.87, p = .049; age-by-valence χ^2 (1) = 5.14, p = .023; age-by-condition-by-valence χ^2 (1) = 2.28, p = .131).

Figure 4.5 **Recognition accuracy for self- and other-judged positive versus negative words plotted against age in years**



Note. Solid lines represent significant linear component of age; dotted lines represent estimated fixed effects of polynomial age (ribbons: 95% confidence interval); data points are participants' mean recognition accuracy.

Retrieval – Reaction times. Participants were faster to correctly recognise self-judged words compared with other-judged words (main effect of condition: χ^2 (1) = 119.44, p < .001; contrast$_{Self–Other}$ = -.19, SE = .02, p < .001) and positive compared with negative words (main effect of valence: χ^2 (1) = 31.62, p < .001; contrast $_{Pos – Neg}$ = -.09, SE = 0.02, p < .001). There were no other significant main effects or interactions.

Associative-matching (shapes) task

Overall, participants showed the SRE in both accuracy and RTs in the shapes task. Participants were more accurate (main effect of condition: χ^2 (1) = 5.58, p = .018; contrast$_{Self–Other}$ = .24, SE = .10, p = .018) and faster to make matching decisions (main effect of condition: χ^2 (2) = 14.05, p < .001, contrast$_{Self–Other}$ = -.05, SE = .01, p < .001) for self-associated compared with other-associated shapes.

There was no change in the size of the SRE with age in either accuracy (interaction condition and age: linear χ^2 (2) = .44, p = .507; quadratic χ^2 (2) = .81, p = .368) or RTs (interaction condition and age: linear χ^2 (2) = 2.12, p = .145; quadratic χ^2 (2) = .07, p = .797).

Relationship between words and shapes SRE

The size of the SRE (mean accuracy for self – mean accuracy for other) for the words task was not associated with SRE for the shapes task (r = -.01, p = .865).

Self-consciousness, social anxiety and self-referential processing of evaluative stimuli

Descriptiveness ratings. Greater social anxiety was related to increased negative and decreased positive judgements about the self but not the other (Prediction 4; interaction social anxiety, condition and valence: χ^2 (1) = 38.96, p < .001; post-hoc contrasts: slope$_{Self\ (Pos)}$ = -.31, SE = .1, p < .001, slope$_{Other\ (Pos)}$ = -.06, SE = .1, p = .364, contrast$_{Self–}$

$_{\text{Other (Pos)}}$ = -.25, SE = .1, p_{Bonf} < .001; slope$_{\text{Self (Neg)}}$ = .42, *SE* = .1, *p* < .001, slope$_{\text{Other (Neg)}}$ = .06, *SE* = .1, *p* = .432; contrast$_{\text{Self–Other (Neg)}}$ = .35, *SE* = .1, p_{Bonf} < .001). Social anxiety showed a quadratic negative relationship with age (quadratic: β = -2.00, *SE* = .91, t = 2.20, *p* = .029).

Public self-consciousness (style and appearance consciousness) was specifically associated with higher negative self-judgements (Prediction 4; interaction public self-consciousness, condition and valence: χ^2 (1) = 4.51, *p* = .034; post-hoc contrasts: slope$_{\text{Self (Neg)}}$ = .21, *SE* = .1, *p* = .015, slope$_{\text{Other (Neg)}}$ = .01, *SE* = .1, *p* = .859, contrast$_{\text{Self–Other (Neg)}}$ = .19, *SE* = .1, p_{Bonf} = .018). Public self-consciousness showed a quadratic negative relationship with age (quadratic: β = -2.80, *SE* = .92, *t* = 3.03, *p* = .003).

Self-reference effect. I assessed whether private self-consciousness (self-reflectiveness and internal state awareness) was associated with an increased self-reference effect in the recognition memory task. There was no interaction between private self-consciousness and condition (Prediction 5; χ^2 (1) = .03, p =.855).

Matrix reasoning and testing group size

There was an association between matrix reasoning score and the quadratic component of age (linear: β = 1.13, *SE* = .98, *t* = 1.15, *p* = .250; quadratic: β = -3.06, *SE* = .98, *t* = -3.13, *p* = 002). Therefore, matrix reasoning score was included as a covariate in all models. Matrix reasoning was associated with better overall recognition memory (χ^2 (1) = 9.78, *p* = .002, β = .14, *SE* = .06, *p* = .002) and was not significantly associated with any other outcomes in the words task. In the shapes task, better matrix reasoning ability was associated with better matching accuracy overall (χ^2 (1) = 5.58, *p* = .018, β = .27, *SE* = .05, *p* < .001) and faster reaction times (χ^2 (1) = 18.54, *p* < .001, β = -.05, *SE* = .01, *p* < .001).

There was a significant association between testing group size and age (linear: $\beta = -73.04$, $SE = 4.97$, $t = -14.69$, $p < .001$; quadratic: $\beta = 12.39$, $SE = 4.97$, $t = 2.49$, $p = .014$). Therefore, group size was included as a covariate in all models. There was a significant effect of testing group size in the descriptiveness ratings model: those who were tested in larger testing group sizes tended to rate words as more descriptive overall than those tested in smaller testing group sizes ($\chi^2(1) = 4.81$, $p = .028$; $\beta = .10$, $SE = .05$, $t = 2.19$, $p = .029$). The effect of testing group size was not significant in any other models.

Discussion

In the current study, females aged 11–30 years, completed two self-referential tasks: a recognition memory task employing evaluative words and an associative-matching task employing neutral shapes. Participants also self-reported their levels of self-consciousness and social anxiety. When stimuli were evaluative (words task), the size of the SRE, namely the tendency to recognise more self-judged words than other-judged words, showed an age-related decrease. When stimuli were neutral (shapes task), there was no age-related change in the size of the SRE, the tendency to make more accurate judgements of self-associated compared to other-associated shapes. In addition, the tendency to judge negative words as descriptive of the self, increased across adolescence, peaking around 19 years, before reducing again in early adulthood. This tendency to rate negative words as descriptive of the self was associated with heightened social anxiety and public self-consciousness. In recognition memory, the magnitude of the positivity bias, the tendency to recognise more positive than negative words, increased across the age range (11-30 years).

Self-reference effect across age

The first prediction, that the SRE would reduce with age, was partially supported by the data. The SRE reduced linearly with age when stimuli were evaluative (in the words task) but not when stimuli were neutral (in the shapes task). The youngest participants in this study (11-year-olds) had recently transitioned to secondary school. This period of transition is associated with major changes to peer networks (Brown, 2013) as well as pubertal changes (Schaffhuser et al., 2017; Simmons et al., 1979) and development in the ability to reflect on the self and others (Dumontheil et al., 2010a; Pfeifer et al., 2009b; Symeonidou et al., 2016a). During this period of transition, adolescents strive to become independent from their parents and discover their own identity (Koepke & Denissen, 2012c). This may elicit uncertainty in or interrogation of the self-concept (Cole et al., 2001). I suggest that this uncertainty might motivate increased self-referential processing, meaning that self-relevant information is more salient and more likely to be remembered. Adolescents may gradually become more certain about their self-concept and therefore show reduced self-referential processing. This might help to explain why I observed an SRE in the words but not the shapes task. The self-relevant words in the recognition memory task may be particularly salient to younger participants as these descriptors can be used to inform their self-concept. In contrast, neutral stimuli arbitrarily associated with the self, as in the shapes task, are not informative and thus might not be particularly salient to the younger participants.

Interestingly, I found that memory performance in general (ignoring condition or valence) remained relatively stable across the age range. It might be assumed that memory performance would improve across adolescence and into early adulthood, although this has not been consistently reported in the literature (Ghetti & Angelini, 2008; Pauls et al., 2013), and several social and self-related cognitive processes have shown nonlinear development with age (Diamond et al., 1983; Somerville et al., 2013b). In the case of self-referential memory, the affective and motivational nature of the task might mean that the younger participants in this study were able to reach a better memory performance than under other encoding conditions.

Negative self-judgements across age

The use of evaluative stimuli in the recognition memory task allowed me to assess how valence influences self-referential processing in adolescence and into adulthood in female participants. Consistent with previous research and my second prediction, I found that negative self-judgements increased across adolescence (peaking at around age 19) and decreased into adulthood. Several explanations for this increase in negative self-judgements across adolescence have been proposed. First, adolescents might transition from relying on parental judgements in childhood, to leaning more on potentially less favourable peer judgements to inform their self-judgements (Brown, 2013; van der Aar et al., 2018). Consistent with this, adolescents tend to endorse the most positive attributes about themselves when taking the perspective of their mother rather than of their friends or their own perspective (Pfeifer et al., 2009). Further, adolescents' self-judgements are harsher when they are asked to compare themselves with a peer, especially in 15–17-year-olds (van der Aar et al., 2018).

In this study, I found that negative self-judgements were associated with greater social anxiety and public self-consciousness. Again, this highlights the importance of the "looking-glass self", that is, our self-identity when taking the perspective of others (Shaffer, 2005), in self-concept development. Further, I found an age-related increase in positive judgements about the chosen other across adolescence, which peaked at around age 23 and was followed by an age-related decrease in the late twenties. If individuals have an inflated positive view of others, this might additionally explain why comparisons with others negatively impacts on self-judgements. In future research, it will be important to further categorise descriptive words into domains. Previous work has shown that the trajectory of positive and negative self-judgements across adolescence may depend on domain, for example, whether participants are asked to judge their academic, social or physical traits (Preckel et al., 2013; van der Aar et al., 2018b).

The results of this study showed an age-related inverted U-shaped curve in negative self-judgements, but did not show the opposite age-related change (i.e. U-shaped curve) in positive self-judgements. This suggests that the positive and negative domains in self-judgements might be independent. This specific age-related change in negative, but not positive, self-judgements has been shown previously (McArthur et al., 2019) and echoes work suggesting that individuals' experience of positive and negative affect may be independent of each other (Diener & Emmons, 1984; Watson et al., 1988).

Positivity memory bias across age

I extended previous work by assessing recognition memory for self- and other-judged positive and negative words. This led to my third prediction, that memory for self-judged negative words would increase across adolescence and then decrease in early adulthood. I found that participants of all ages showed a positivity bias in recognition memory, remembering more positive words compared with negative words. The magnitude of this positivity memory bias increased linearly with age, such that younger participants remembered more negative and fewer positive words than did older participants.

This age-related increase in positivity memory bias suggests that positive person-relevant trait words become more salient and negative person-relevant trait words become less salient across adolescence and early adulthood in female participants. Previous work on the positivity memory bias in adolescence has been mixed, with some authors suggesting a negativity bias (Quas et al., 2016; Bone et al., 2021) and others showing different valence biases according to whether free recall or recognition was assessed (Neshat-Doost et al., 1998). Here, I showed that, when words were encoded through self- and other-judgements, there was an age-related increase in the positivity memory bias. This positivity bias may reflect a motivation to uphold a positive view of the self and others (i.e. self-serving bias, Miller & Ross, 1975; or an optimism bias, Sharot, 2011), which may develop across adolescence, at least according to the results presented here.

A lower positivity bias in (self-referential) memory has previously been shown to be associated with depressive symptoms during adolescence (Connolly et al., 2016; Hammen & Zupan, 1984b). Adolescents, relative to other age groups, are at heightened risk of developing mental health conditions such as depression and the reason for this heightened risk is still not well understood (Kessler, Amminger, et al., 2007). Further, low self-esteem has been shown to prospectively predict onset of depression in adolescence (Orth et al., 2008b; Rieger et al., 2016a) and self-hatred has been shown to be a central symptom in adolescent depression (Mullarkey et al., 2019b). Developing a positive self-concept during adolescence may buffer against mental health problems (Neff & McGehee, 2010). Therefore, future work should aim to assess how emerging self-referential processes and memory biases are associated with the onset of depressive symptoms during this critical period of development.

Limitations and future directions

I recruited a female-only sample and the results might not generalise to males. It is unclear whether there are consistent gender differences in self-referential processing. Previous studies on gender differences in the self-reference effect (Bentley et al., 2017) and on self-judgements (Jacobs et al., 2002; McArthur et al., 2019b; van Buuren et al., 2020) have been mixed. In other studies, gender differences were not investigated or a single-gender sample was recruited (Ray et al., 2009b) as in the current study. Therefore, further work is needed to investigate whether the results found here replicate in males.

Another limitation of the study was that verbal word span was not measured. Verbal word span could conceivably affect memory performance on the recognition memory task overall. However, words were randomly assigned to target (shown at encoding, to-be-remembered) and distractors (shown only at retrieval), and randomly split across the self and other-judged conditions. Therefore, one would not expect verbal word span to have a significant impact on memory performance between the factors of interest. One may also expect that verbal word span would be associated with performance on the Matrix Reasoning task and the results presented here survived when including Matrix Reasoning score as a covariate.

In previous research, participants were typically provided with another famous figure or fictional character to give descriptiveness ratings about (Dégeilh et al., 2015a; Pfeifer et al., 2007, 2013) or participants were asked to answer about a relative or a peer (Ray et al., 2009b; van der Aar et al., 2018b). Here, I asked participants to choose a famous person or fictional character themselves, in order to ensure that they were familiar with them and to increase engagement with the task (I assumed participants would be more interested in answering about someone of their choosing). I asked participants to rate the familiarity and likeability of the person they chose and found that participants reported being familiar with and liking the person they chose. I was also able to report the profession of the person chosen or whether they were a fictional character. However, I did not ask any further details about the participants' views of their chosen person and future work should assess how the effects reported here are mediated by factors such as how similar the participant feels to or whether they admire their chosen person.

Conclusions

Through adolescence, young people seek to construct their self-concept. In this study, when stimuli were evaluative, the self-reference effect decreased across the age range studied (11–30 years). When stimuli were neutral, the self-reference effect remained stable across age. I found that valence was an important factor in self-referential processing. The tendency to rate negative words as descriptive of the self showed an age-related increase across adolescence, peaking around 19 years and decreasing in early adulthood. Finally, I identified an age-related increase in the magnitude of a memory positivity bias. These findings suggest that adolescents may have cognitive biases that shift their attention towards information that can help them construct a sense of self but might be particularly focussed on negative aspects of themselves and others. Further research is needed to understand why self-judgements become increasingly negative in adolescence and how memory biases towards negative stimuli impact on self-concept development across the lifespan.

In the next chapter I segue from “learning what we’re like” to “learning what we like”. In this way, I further explore adolescents’ motivation for self-concept development and how this interacts with their developing abilities to reflect on the self. I will investigate how adolescents develop and refine their estimates about their own preferences. So far, I have shown that the onset of adolescence is marked by an increase in the ability to reflect on our own decisions, increased autonomy in the decisions that we make and increased memory for self-referent information. In the next chapter, I ask how the act of making independent decisions itself may allow adolescents to reflect on and learn about their own preferences.

Table 4.5 **Word stimuli for the recognition memory task.**

Positive words

patient	independent	relaxed	excitable	cautious	restless	calm	likable
talented	energetic	courageous	self-confident	self-critical	daring	popular	persuasive
ambitious	neat	smart	sociable	tidy	polite	optimistic	proud
brave	brilliant	enthusiastic	creative	lively	imaginative	truthful	serious
considerate	kind	happy	intellectual	responsible	cheerful	sensible	easy-going
musical	peaceful	thoughtful	witty	intelligent	trustworthy	friendly	generous
unlucky	scientific	artistic	helpful	honest	interesting	shy	sympathetic
emotional	wealthy	nice	reliable	attractive	open-minded	talkative	clever
quiet	unpredictable	wise	athletic	strong	leader	confident	understanding

Negative words

jealous	greedy	unfriendly	thoughtless	cruel	selfish	impatient	liar
gossipy	annoying	self-centered	careless	nosey	boastful	stupid	untrustworthy
short-tempered	unforgiving	lazy	pessimistic	unreliable	unsympathetic	worrier	unkind
clumsy	unpleasant	insecure	noisy	unhealthy	unimaginative	irresponsible	impolite

unemotional	rebellious	unpopular	unhappy	daydreamer	stubborn	childish	bossy
sarcastic	dishonest	sad	boring	foolish	forgetful	messy	irritating
weak	rude	untidy	moody	plain	lonely	unintelligent	oversensitive

Note. For each participant, four lists (four columns in the table) were selected at random to be displayed during the encoding stage (two lists assigned to self-judgement, two lists assigned to other-judgement; target words). The other four lists were used as distractors in the retrieval stage, meaning all eight lists were displayed at the retrieval stage. In both stages, words were displayed sequentially in a random order.

Chapter 5

Development of value refinement and its associations with depressive symptoms in adolescence

Part of this chapter has been published as:

Moses-Payne, M. E., Lee, D. G. & Roiser, J. P. (2024). Do adolescents use choice to learn about their preferences? Development of value refinement and its associations with depressive symptoms in adolescence. *Child Development*.

Abstract

Adolescence is an important developmental period, during which young people transition from being dependent on their caregivers to becoming independent young adults. A fundamental feature of independent decision making is the ability to hold stable and certain estimates of one's preferences. Previous research has suggested that in adults such preferences occur in part through refining their value estimates through the process of choice. This study aimed to investigate age-related differences in value refinement through choice. Further, I examined whether depressive symptoms in adolescence could potentially disrupt this process. Finally, I hypothesized that younger adolescents would find this reduction of uncertainty through choice particularly rewarding and I assessed this using a novel task. Adolescents aged 11–18 (N = 214) completed two experimental tasks. In the choice-induced preference change (CIPC) task, participants were asked to rate multiple activities, choose between pairs of activities and rate those activities again. In the control condition, adolescents only made preference choices between pairs of activities after completing both sets of ratings. In the switching task, participants were asked to divide their time between a tedious attentional task for monetary reward or an engaging self-reference choice task for no monetary reward. Through this, I could assess the amount of reward participants were willing to forgo in order to complete choices about their own preferences. In the CIPC task, I showed that adolescents refined their value estimates by uprating chosen activities and downrating unchosen activities, especially when preference choices were made between ratings. When controlling for changes in ratings in the control condition, I showed that value refinement through choice deliberation increased across

the age range. In contrast to my predictions, depressive symptoms did not disrupt this process; in fact, depressive symptoms were associated with increased value refinement. However, in spite of this, depressed adolescents remained less certain about their values and less confident in their choices. I did not find any age-related change in the amount of reward adolescents were willing to forgo to answer preference questions about themselves. This study emphasizes the importance of independent decision making in the formation of self-concept during adolescence. Further research on the processes that adolescents use to learn about themselves and how depressive symptoms affect these processes could enable more effective support for promoting the formation of a positive and stable self-concept.

Introduction

Adolescence is a time of increasing independence and autonomy, during which young people start to make more decisions for themselves. While children's daily activities tend to be determined by their caregivers, across adolescence young people increasingly make more of their own decisions – what clothing to wear, what music to listen to, and where and with whom to spend time. As a result of this greater autonomy in decision making, adolescents begin to explore different options, but the processes through which preferences develop during this period are poorly understood.

Typical behavioural tendencies during adolescence such as risk taking (Leather, 2009), forging new friendships (Berndt & Hoyle, 1985) and exploring novel environments (Saragosa-Harris et al., 2022), suggest that adolescents actively seek out opportunities to make independent decisions. This may be because novelty affords rapid trial-and-error learning about the self and the world (Ciranka & van den Bos, 2021; Lloyd et al., 2021). In this way, making independent decisions may allow young people to learn about their self-concept, a key feature of adolescence (Harter, 2012). At the same time, key cognitive competencies that support effective learning from decisions may still be maturing during this period. Previous work has demonstrated age-related changes during adolescence in the ability to reflect on decisions (Chapter 2; Weil et al., 2013) and to ignore inaccurate advice or influence from others, especially peers (Schwarz & Roebers, 2006). In the current study, I sought to investigate how young people's capacity to learn about themselves through choice evolves throughout adolescence.

Previous work has used a two-alternative forced-choice task known as the free-choice paradigm (FCP) to demonstrate how preferences can shift after making choices even when their consequences are not directly experienced. In the FCP, participants are initially asked to make value ratings for multiple items, for example, snacks. Items are then paired in a manner that produces both ‘easy’ (differently rated) and ‘difficult’ (closely rated) choices, and participants are asked to choose between paired items, for example, whether they would rather a pretzel or a chocolate bar. Finally, participants are asked to rate all items a second time. A consistent finding is that most participants display ‘spreading of alternatives’ (SoA): items that were chosen are re-rated more favourably, with the opposite pattern for unchosen items. This ‘choice-induced preference change’ (CIPC) has a substantial effect size and has been widely replicated, even being reported to persist over several years (Sharot et al., 2012). CIPC has been demonstrated in infants and children (Silver et al., 2020) and even non-human primates (Egan et al., 2007) but the developmental trajectory of SoA in adolescence is largely unknown.

For many years, SoA was interpreted as reflecting a reduction in cognitive dissonance. This account posits that once a choice is made, any negative feelings about the chosen item (or positive feelings about the unchosen item) will create an unpleasant state of cognitive dissonance because of the contradiction between participants’ behaviour and their feelings. In this account, in order to reduce dissonance, participants engage in a post-hoc justification of their choices by increasing/decreasing their value estimates of the chosen/unchosen items, respectively. More recently, an alternative explanation has been proposed, based on the notion of value refinement (D. Lee & Daunizeau, 2020; D. G. Lee et al., 2023; D. G. Lee & Daunizeau, 2021). There are two key differences between this explanation and the cognitive dissonance account: first, changes in value estimates occur *during* the process of choice, rather than in post-hoc deliberation *after* a decision has been reached; and second, that choice leads not only to perturbation in value estimates but also to reduction in uncertainty. In support of this view, SoA was found to be strongest when participants were least certain about their initial value ratings but were able to reach a confident choice (D. Lee & Coricelli, 2020; D. Lee & Daunizeau, 2020; D. G. Lee & Daunizeau, 2021). In contrast, a cognitive dissonance account, would predict greater dissonance (and therefore stronger SoA) when participants were highly certain about their initial value ratings but made an inconsistent (low confidence) choice. Lee & Daunizeau (2020) argued that the process of deliberating over choice alternatives allows participants to become more precise in their evaluations. Comparing options may highlight aspects of the items that were not considered during the ratings. When choices are difficult (i.e. similarly rated or with uncertain ratings), this encourages participants to reassess the options and gain certainty over their value estimates until they can reach a satisfactory level of choice confidence, as suggested by a recent simulation study (D. G. Lee et al., 2023).

An important challenge to both the value refinement and cognitive dissonance accounts came from Chen and Risen (2010), who questioned whether SoA really reflected any underlying change in preferences and argued instead that it could arise due to a simple statistical artefact. This argument hinges on the idea that participants are not certain about values, and that their reported values are estimates drawn from distributions. It is therefore possible that two paired items could initially have been rated quite similarly, even though the means of their distributions were quite different. When pairing choice alternatives, the value rating for the more-liked item is likely to have been drawn from the lower end of its distribution and the value rating for the less-liked item from the upper end of its distribution. The subsequent choice between these two items would then typically reflect the direction of the difference in the underlying value estimates, with the more-liked item more likely to be chosen; however, when participants are asked to rate the two items again there will be a regression to the means of the respective distributions with respect to the initial ratings, with the value rating of the chosen item being rated more favourably (moving away from the lower tail of the higher distribution) and the opposite pattern for the unchosen item (moving away from the higher tail of the lower distribution). This statistical artefact might therefore produce an apparent SoA, even without a shift in the underlying value distributions. Importantly, Chen and Risen (2010) demonstrate that apparent SoA can be observed using a design where no choices are made between the two sets of ratings but instead after both ratings have been made. In this case, it is clearly impossible for the change in ratings to have been 'induced' by the choice.

This statistical artefact account has been challenged by a number of studies using controlled designs to show that SoA is stronger when choices occurred between the ratings rather than after, when choices were made between the ratings but were made by a computer (Izuma et al., 2010; Salti et al., 2014), when choices were implicit rather than explicit (Alós-Ferrer et al., 2012) or when participants were blind to the choices as they made them (Enisman et al., 2021; Izuma et al., 2015; Johansson et al., 2014; Luo & Yu, 2017; Miyagi et al., 2017; Nakamura & Kawabata, 2013; Sharot et al., 2010; Taya et al., 2014). Another challenge was recently demonstrated using simulation analysis showing that this explanation cannot account for many patterns of data observed in the FCP (D. G. Lee & Pezzulo, 2023).

The value refinement account of SoA suggests that individuals can use choice to learn about (i.e. reassess and refine) their own preferences. Here I aimed to test whether adolescents learn about their preferences through making choices. I hypothesised that younger adolescents may be drawn towards opportunities to make autonomous decisions, because they are less certain about their preferences and thus are more motivated to refine them. This lower certainty in value estimates should lead to greater deliberation during the choice phase of the FCP, and greater value refinement as a result. I therefore predicted that younger adolescents would show a greater SoA after preference choices, and that this SoA would show an age-related decline as adolescents gain certainty over their preferences.

Previous work has suggested that learning and reducing uncertainty is intrinsically rewarding (Gottlieb et al., 2013). This intrinsic motivation to reduce uncertainty is evident as young as infancy; infants selectively attend to events that violate their expectations (Dunn & Bremner, 2017; Wu & Gweon, 2019; Henderson & Woodward, 2011). As soon as children develop language capacities, they begin to ask questions – about eighty per hour according to transcripts analysed by Chouinard et al., (2007). This curiosity underlies learning in childhood and beyond (Shah, Weeks, Richards, Kaciroti, 2018). In adolescence, there may be a particularly strong motivation to learn about the self and the social world (Andrews et al., 2021; Hoffmans & Van den Bos, 2022; Crone et al., 2022). According to early work on identity formation in adolescence, young people transition through an 'identity moratorium' phase during which they are especially motivated to explore different aspects of their identity (Marcia, 1980). However, there have been few attempts to quantify the rewarding nature of self-concept exploration in order to assess age-related changes in motivation to reduce uncertainty about the self.

According to a value refinement account, individuals can use choices to reduce their uncertainty around their own preferences. Therefore, I aimed to test whether value refinement was rewarding. In order to measure adolescents' curiosity to learn about their preferences through choice, I designed a novel task to quantify the amount of reward adolescents were willing to forgo in order to complete preference-based choices. The task was adapted from the Academic Diligence Task (Galla et al., 2014; Andrews et al., 2019). Participants could choose between a tedious task on which they could earn monetary reward (based on Sustained

Attention to Response Task - SART; Robertson et al., 1997) and a quiz-based task on which they could not win any monetary reward. Participants completed the task in three blocks of four minutes each. In each block the quiz-based task available to participants contained different choices: self-preferences, other-preferences and colour choices. In the self-preferences quiz task, participants answered preference-based choices about themselves. For the other-preferences choices, participants were asked to pick a family member at least 10 years older than them to answer about. For the colour choices, participants were asked to pick the image that was least colourful. Through this, I could calculate the proportion of time participants spent on the quiz task, which is equivalent to the monetary reward (in pence) that participants were willing to forgo in order to complete it. I made the following predictions: 1) there will be an age-related decrease in time spent on the self-preferences quiz task (controlling for time spent on the colour quiz task); 2) greater time spent on the self-preferences quiz task (but not the other-preferences or colour quiz task) will be associated with greater SoA due to value refinement.

Adolescence is also marked by the onset of mental health problems such as depression (Kessler, Angermeyer, et al., 2007; Solmi et al., 2022). Previous work has shown that self-views are important predictors of and central symptoms of adolescent depression (Mullarkey et al., 2019a; Orth et al., 2008a; Rieger et al., 2016b). Characterising the developmental trajectory of self-relevant learning mechanisms such as SoA may help us to better understand how to support the development of a positive self-concept. A growing literature suggests that altered decision making and value formation in adolescence may indicate risk for depression (Forbes et al., 2007; Forbes & Dahl, 2012). For example, a longitudinal study on 11-year-old boys demonstrated that a lower tendency to choose high-probability high-reward options was associated with depressive symptoms one year later (Forbes et al., 2007). When rewards do not elicit typical approach behaviours, forming a value estimate may be more challenging, therefore increasing uncertainty. Relatedly, a core symptom of depression is difficulty in making decisions: depressed patients often report indecisiveness (Leykin & DeRubeis, 2010). One possible driver of indecisiveness in depression is lower decision confidence; accordingly, depressive symptoms have been associated with lower confidence in the absence of feedback (Rouault, Seow, et al., 2018) and greater post-decision adjustment of confidence in light of new evidence (Moses-Payne et al., 2019). Preliminary evidence in adults suggests depressive symptoms may be associated with alterations to CIPC (Miyagi et al., 2017), but mechanisms of certainty and confidence have not yet been assessed. I hypothesised that adolescents with more depressive symptoms would be less able to use choice deliberation to gain certainty over their value estimates, and so would show lower SoA, and would not be able to resolve their uncertainty in a confident choice. Therefore, I made the following predictions: depressive symptoms would be associated with lower initial value certainty, a smaller increase in value certainty after preference choices, a smaller SoA, and lower confidence in preference choices. Further I hypothesised that, if depressive symptoms were associated with less value refinement through choice, depressed adolescents would enjoy making choices less. Therefore, I predicted that depressive symptoms would be associated with less time spent on the self-preferences quiz while controlling for general preference for the tedious task with time spent on the colour quiz.

Methods

Participants

Participants were recruited from secondary schools in London, UK. For participants under 16 years of age, I gained parental consent and participant assent. Participants over 16 years of age consented to take part themselves. Each participant was given a voucher valued between £7-9.50 depending on their performance in the Switching task. The study was approved by the University College London Research Ethics Committee (ID: 14261/001).

I recruited 242 participants and analysed data from 214 participants. Participants were excluded if the correlation between their first and second ratings was less than .5 (n=8) or if they failed at least three times in at least two instruction quizzes (n=4) or for technical issues (incomplete data, n=14; images did not load, n=1). One participant withdrew consent to take part in the study.

Participants were excluded from Switching task analysis if they missed more than 10% of target trials in the SART (and they had viewed at least 10 target trials, n = 8). No participants had more than 6% false alarm trials. I analysed Switching task data from 234 participants.

Participants were aged 11–18 (11.29–18.51, M=14.96). This age group was chosen to span a wide developmental window but also to ensure testing conditions were similar across participants (all participants took part in groups in classroom settings and were paid with vouchers).

Participants' indices of multiple deprivation (IOMD) were estimated according to their postcode using 2019 UK Government deprivation data (https://imd-by-postcode.opendatacommunities.org/). This measure is based on seven domains of deprivation with the following weights: income deprivation (22.5%), employment deprivation (22.5%), education, skills and training deprivation (13.5%), health deprivation and disability (13.5%), crime (9.3%), barriers to housing and services (9.3%) and living environment deprivation (9.3%). I included participants with IOMD spread across the entire range (1–10; M=4.83).

Parents provided ethnicity for children under 16 and participants over 16 provided ethnicity for themselves. Ethnicity was divided into five categories: 1) Asian, Asian British or Any other Asian background (19%); 2) Black, African, Caribbean or Black British (21%); 3) Mixed or multiple ethnicities (9%); 4) Other ethnic group (Arab or Latin American; 8%) 5) White (26%). Seventeen percent of participants' ethnicity was missing.

CIPC Task

Piloting. I completed three pilot studies during the development of the task with 18–24-year-olds (total N=224) recruited via the online recruitment platform, Prolific. Through this process, I extended previous work to design a paradigm that: 1) used a within-subjects design to contrast two conditions: i) Ratings, Preference choices, Ratings - RPR - and ii) Ratings, Colour choices, Ratings, Preference choices - RcRP; 2) controlled for exposure to the stimuli; and 3) included instruction quizzes to ensure participants understood the task. I also optimized the number of trials to ensure adolescents could complete the task in a single session and used pilot data to set the exclusion criteria.

Stimuli. Stimuli were 80 images and descriptions of age-appropriate activities, for example, ten-pin bowling, visiting a theme park, or playing football. Activities were generated by 117 11–14-year-olds to ensure that they would be appropriate and familiar to adolescent participants. To prompt the generation of activities, I asked "Can you think of activities you would do on a Saturday if there was no pandemic? Think of at least three fun and three boring activities". Matching images were gathered from the copyright-free online database, Unsplash. For each participant, 40 image-description pairs were selected at random.

The task was implemented using Javascript, HTML and CSS and hosted on Gorilla.sc.

Experimental design. Participants completed the task in four parts: 1) value ratings; 2) choices (two blocks: preference and colour, with the block order counterbalanced); 3) value ratings and 4) preference choices. Task display and procedure are shown in Fig. 5.1.

Instructions. Participants were instructed that they should imagine it was Saturday, sunny and that there was no pandemic. Before starting the task, participants were instructed on the value and confidence rating scales. Participants were instructed to think carefully about their ratings. After making their ratings, participants were instructed on the choice section of the task and were asked to complete a three-question quiz on the instructions (used as an exclusion criterion). If they failed the quiz, participants returned to the start of the instructions. Participants were also asked to complete an instruction quiz whenever the choice blocks changed, to ensure they understood whether they needed to answer according to preference or colour. The number of times participants needed to restart the instructions was recorded and used as an exclusion criterion.

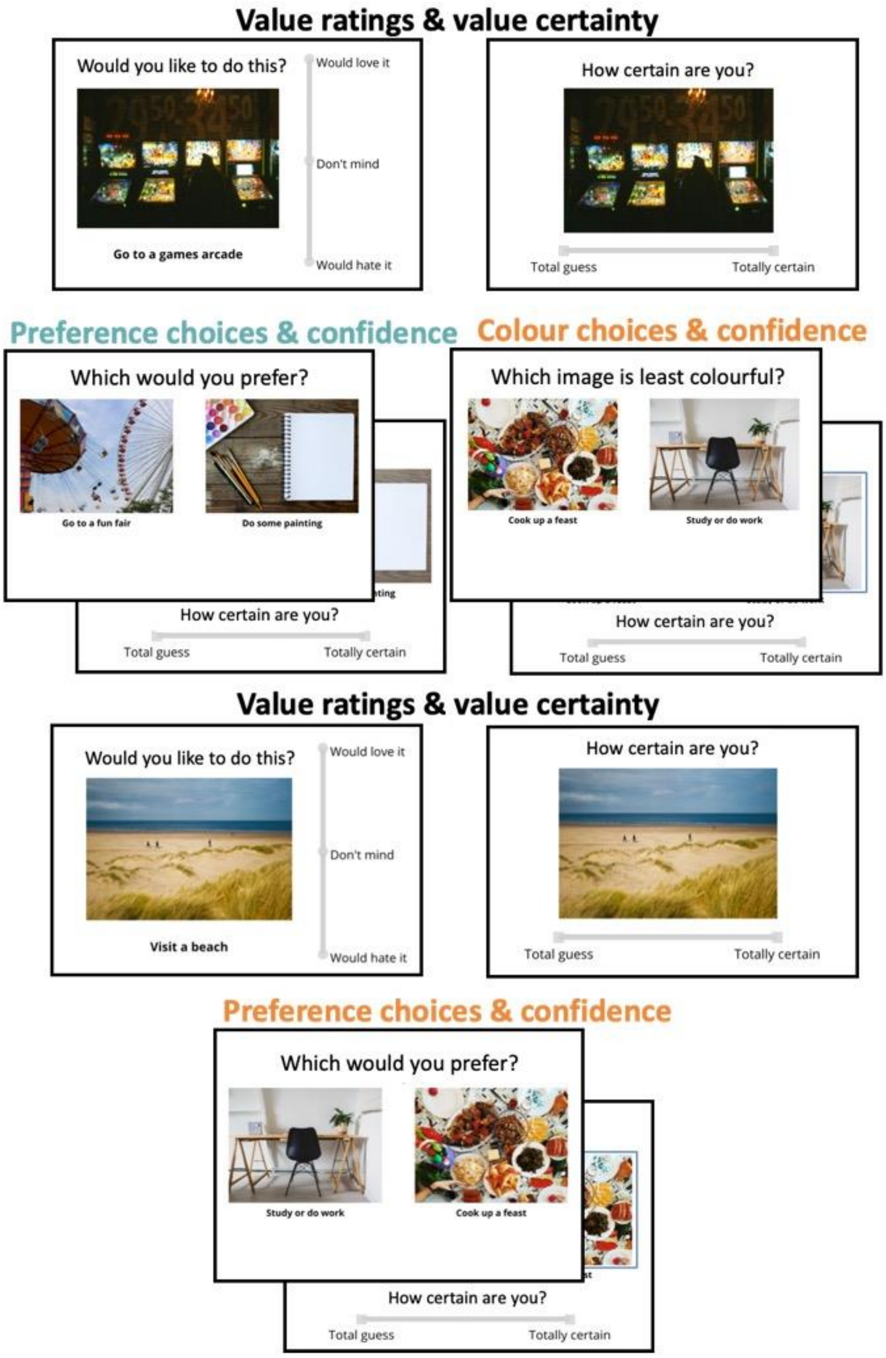
Ratings. During the first and third parts of the task, participants were asked to make a value rating and associated certainty rating for all 40 activities. Participants viewed an image and description of the activity in the center of the screen. For the value ratings, participants were prompted with "Would you like to do this?" and rated the activity on a scale from 0 to 100. The scale had labels at 0 "Would hate it", 50 "Don't mind" and 100 "Would love it". For the certainty ratings, participants were prompted with "How certain are you?" and rated their certainty on a scale from 0 to 100. The scale had labels at 0 "Total guess" and 100 "Totally certain". To avoid anchoring, the slider tooltip remained hidden until the participant's first click. The tooltip numerical value was not displayed to participants.

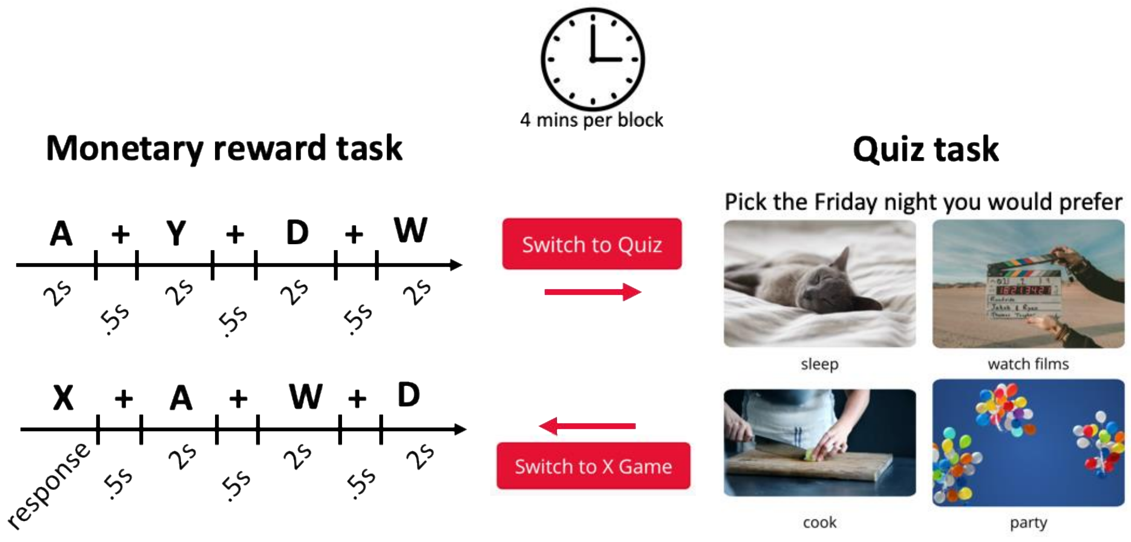
Choice pairing. After the initial ratings, activities were paired to create 20 choice trials. I aimed to create 10 'close' pairs (activities that were similarly valued) and 10 'distant' pairs (activities that were valued differently) of activities. Activities were binned into 20 equally-sized bins (width of 5 points) according to their initial rated values. To create close pairs, a single bin was selected at random and two activities from this bin were paired. To create distant pairs, two bins were selected at random, one item was taken from each bin and paired. Close pairs were created initially, followed by distant pairs. If there were insufficient bins to create all 10 distant pairs, activities were selected from the same bin so that participants were always presented with a minimum of 10 close pairs. The number of pairs of activities that were initially rated within 5 points of one another ranged from 10–17 (out of 20 choices; M=12.25, SD=1.82). Pairs of activities were displayed in a random order (randomly allocated to either a preference choice or colour choice in part two of the task) and the item with the highest value was randomly allocated to the left or right side of the screen.

Choices. During the second and fourth part of the task, participants made choices between pairs of activities. In the second part, participants completed 20 choice trials: 10 in which they chose according to which activity they would prefer (which I term "preference" choice) and 10 in which they chose which image was least colourful (which I term "colour" choices). In the preference choice block, participants were presented with two images and image descriptions side-by-side on the screen and were prompted with "Which would you prefer?". In the colour choice block, the choice display was identical except participants were prompted with "Which image is least colourful?". In both blocks, participants responded by clicking on the activity image. Once the image was clicked, a confidence scale appeared. Participants were prompted with "How certain are you?" and rated their confidence from 0 "Total guess" to 100 "Totally certain". The order of the choice blocks was counterbalanced between participants. During the final part of the task, participants chose which activity they would prefer for the 10 choice pairs that had previously been presented during the colour choice block in part two. Otherwise, the procedure was identical to the preference block in the second part of the task.

Conditions. Stimuli were split into two conditions. First, the RPR [Ratings, Preference choices, Ratings] condition, in which participants rated the activities, made preference choices between the activities and then re-rated the activities. These activities did not appear in the final part of the task. Second, the RcRP [Ratings, Colour choices, Ratings, Preference choices] condition, in which participants rated the activities, made colour choices between the activities, re-rated the activities and then made preference choices between the activities. All participants completed the task with all activities in a within-subjects design. All activities were paired using the same algorithm irrespective of condition (see Choice pairing).

Figure 5.1 **CIPC and Switching task procedures**





Note. Top panel, CIPC task: Forty activities were randomly selected from a set of 80 activities and presented in a random order. Participants made 40 initial ratings, and 10 choices in each condition. Activities presented in the colour choices between ratings were presented again in the final preference choices. Choices were completed in blocks. The order of preference choices and colour choices was counterbalanced. The order of activities in the second ratings was randomized. Bottom panel: Switching task. During the monetary reward task, participants viewed a stream of letters in the center of the screen. When participants viewed an X, they were instructed to respond by pressing space. If they successfully responded, participants saw "5p" in green on screen for the remainder of the trial time after button press. In the quiz task, participants selected one of four choice options displayed in a grid. There were three rounds of 4 minutes each with a different quiz type in each block: self-preferences, other-preferences and colour choices. At any given time, participants could switch between tasks by pressing a red button at the bottom of the screen.

Switching task

Piloting. I completed three pilot studies (total N = 160) to investigate the effect of reward size on behaviour in the switching task. Pilot participants were 18–25-year-olds recruited via the online recruitment site Prolific. All pilot tasks shared the same design as the current experiment but differed in the size of the reward available in the SART part of the task. Participants were rewarded either two, five or ten pence for reward trials. Five pence was ultimately selected as the reward size for the developmental study. Five was selected because two pence did not produce any differences across conditions and five and ten pence both showed a similar pattern of results.

When the reward rate was 5p or 10p, participants spent more time on the self-preference and other-preference quiz than the colour quiz (5p: self vs. colour: $t(63) = .97$, $p = .336$, $d = .12$; other vs. colour: $t(63) = 3.08$, $p = .003$, $d = .39$; self vs. other: $t(63) = -1.91$, $p = .060$, $d = .24$; 10p: self vs. colour: $t(52) = 1.86$, $p = .068$, $d = .26$; other vs. colour: $t(52) = 2.61$, $p = .012$, $d = .36$; self vs. other: $t(52) = -.29$, $p = .773$, $d = .04$).

Stimuli. For the SART portion of the Switching task, distractor stimuli were the letters A, Y, W, D and the target stimuli was an X.

The stimuli in the Quiz portion of the Switching task were question and image-description pairs of activities, objects and locations. For each question there were four image-description items as responses. Activities were selected so as not to overlap with the activities in the CIPC task. Images were gathered from Unsplash.

Experimental design.

Instructions. Participants were instructed that they were able to switch between two tasks – the X game (SART) and the Quiz game. To explain the SART, participants were told they would see a stream of letters, one at a time and that they needed to press the space bar whenever they saw the letter X. They were told that when they pressed space when there was an X on the screen they would win 5p. They were also instructed that if they pressed space on any other letter they would get a 'time out', where they could not do anything. Participants were then shown a video of someone playing the X game before being asked a catch question 'True or false: To win bonus payment, I need to press the space bar whenever there is an X on screen'. If they answered incorrectly they were given the message 'Incorrect! Try again.', and were asked to complete the question again. Participants were then told that while playing the X game they would always have the option of switching to the Quiz game by pressing a button, and they were shown an image of the button they would need to press. Participants were then instructed on the 'Quiz game'. They were told that they would pick between four options for each questions and that questions would either be about your own preferences, someone else's preferences or to make choices about which image was least colourful. Participants were then explicitly instructed that they would not be able to win any bonus money while playing the Quiz game. Participants were also shown a video of the Quiz game. Participants were told they would be able to switch from the Quiz back to the X game 'whenever you like' by pressing a button. They were told each section would last 4 minutes. Finally, participants were told if they spent more than a minute on the X game at the start of the task they would be automatically switched to the Quiz game 'just so you get a chance to see what the quiz questions are'. The final catch question participants were given was: ‘True or false: I can switch between the X game and the Quiz (and back again) whenever I like AND as many times as I like’. At the start of each section, participants were told the condition they were in by instructing participants that the questions would be about ‘your own preferences’, ‘the preferences of a person you choose’ or ‘which image is least colourful’.

Selecting ‘Other’ person. Participants were asked to select someone who was a member of their family, at least 10 years older than them and someone that they knew well. They were given the following examples: mum, dad, step-mum, step-dad, aunt, uncle or cousin. Participants were asked to enter the relation of the person they chose, so that quiz questions could be presented as e.g. ‘which holiday type would your {mum} prefer?’.

SART – The X game. Participants were presented with a single letter in the center of the screen for 2000 ms followed by a fixation cross for 500 ms. Letter streams were pseudorandomized by selecting from 3 lists of letters. The number of letters presented between each target stimulus was taken from a flat random distribution between 3–7, so that on average there were 5 trials (i.e. 12500 ms) between each target stimulus. If participants pressed the space bar during a target trial (when an X was displayed on the screen) then ‘5p’ was displayed in green for the rest of the duration of the trial. If participants pressed the space bar on any other trial, ‘You pressed when there was no X! You get a timeout!’ was displayed on the screen for the remainder of the trial plus 2500ms (the same duration as a single trial).

Longer trial times were deliberately selected to ensure all participants were able to perform at 100% accuracy and therefore match the reward rate between participants. The reward rate meant that participants could win a maximum of £1 per Switching task block.

Quiz task. Each quiz question was presented for 800ms followed by the four choice options, one at a time (faded in) for 700ms each. Choice options were disabled until 100ms after all options had been presented, meaning that participants were unable to terminate the question early. Therefore, each quiz question trial lasted for 3700ms plus the participant's reaction time.

Switching. Participants could switch at any point during the task, by clicking a large labelled red button at the bottom of the screen. Switching occurred in 100ms. If participants did not switch from the SART to the quiz task after 1 minute of the block, they were automatically switched to the quiz task. Participants were instructed that this would occur but that they could switch back at any time.

Blocks. Participants completed the Switching task in three blocks of four minutes each. Each block had the opportunity to switch to a different quiz condition: self, other or perceptual. In the 'self' block, participants had the opportunity to switch to instructions of the format 'pick the {object, location, activity} that you would prefer'. In the 'other' block, questions were of the format 'pick the {object, location, activity} that your {chosen person} would prefer'. In the 'perceptual' block, questions were of the format 'pick the {object, location, activity} picture that is least colourful'.

Switching task feedback

After completing all parts of the experiment, participants were asked to rate how much they enjoyed each part of the switching task on a scale from 0 'Hated it' to 100 'Loved it': i) the X game, ii) The quiz – answering about myself, iii) – answering about the other person and iv) – answering about the colour of the images. Participants were then reminded that they were able to switch between the X game and the quiz game and that they were able to win money on the X game but not the quiz game.

They were then asked for free text responses to three prompts: Why did you spend time on the quiz about i) your own preferences ii) the other person's preferences and iii) the colour of the images.

Questionnaire

Participants completed the Mood and Feelings Questionnaire – Short Form (MFQ-SF; Sharp et al., 2006), which consists of 13 items. The MFQ-SF has been validated in 11–18-year-olds (Rhew et al., 2010; Sharp et al., 2006; Turner et al., 2014) for the measurement of depressive symptoms. The total score was used in analyses, and missing values (17 participants with 1 missing value; 3 participants with 2, 3 and 5 missing values respectively; 1 participant with 12 missing values) were imputed using the mean of completed items. Five participants did not complete the MFQ-SF.

Non-verbal reasoning

Participants completed the nine-item abbreviated version of the Raven Standard Progressive Matrices (Bilker et al., 2012).

Overview of procedure

Participants initially completed consent (over-16s) or assent (under-16s). They then completed the two experimental tasks in a counterbalanced order followed by the Raven's matrices and finally the questionnaires. The order of the tasks was counterbalanced but the Raven's matrices and questionnaires were always presented after the tasks.

Statistical analysis

Spreading of Alternatives

The magnitude of participants' CIPC was calculated using the SoA metric:

$$SoA=[rating\#2 - rating\#1]_{chosen} - [rating\#2 - rating\#1]_{unchosen}$$

SoA was calculated for all choice pairs. Activities were categorized as chosen or unchosen according to preference choices in part two (for the RPR condition) or part four (for the RcRP condition) of the task (ignoring colour choices for the latter). For trial-level mixed-effects analyses, I used the trial-level SoA and marked each score as RPR or RcRP. For linear regression analyses, I calculated two separate scores – SoA-RPR and SoA-RcRP – by taking the mean SoA value across all pairs of activities in each condition for each participant, as well as a difference score (SoA-RPR minus SoA-RcRP).

Statistical models

For details of model implementation and comparison see Statistical Methods.

In this chapter, included the following covariates: sex, ethnicity, index of multiple deprivation, number of participants in the testing room and Raven's matrices score. When constructing the models, I initially tested each covariate individually against the outcome of interest. I then included only covariates that were significantly associated with the outcome of interest in each model (see Table 5.1 and Table 5.2 for model equations). I included random intercepts grouped by participant.

CIPC analysis. For the models of choice confidence, value certainty and value certainty updating, the most parsimonious model included a second-degree polynomial (linear & quadratic) term for age. All other model comparisons showed that the most parsimonious model included a reciprocal term for age (age^{-1}; see Table 5.1 for model equations).

Switching task analysis. For value certainty, the third-degree polynomial (including linear, quadratic and cubic components of age) was not a significantly better fit than the second-degree polynomial (linear and quadratic components of age; $\chi^2(1) = .73$, $p = .394$) but the second-degree polynomial was a significantly better fit than the model containing reciprocal age ($\chi^2(1) = 5.27$, $p = .022$). For choice confidence, the third-degree polynomial fit was not better than the second-degree polynomial ($\chi^2(2) = .66$, $p = .719$) and the second-degree polynomial was not better than the next best-fitting model, which contained reciprocal age ($\chi^2(2) = 6.54$, $p = .038$).

Table 5.1 **Model equations: Choice-induced preference change.**

	Mixed effects models		
	Dependent variable	**Fixed effects of interest**	**Covariates**
Model 1a & 1b	Spreading of Alternatives	a) Value difference, Value certainty, Choice confidence b) Value certainty * Choice confidence	
Model 2a & 2b	Spreading of Alternatives	Age * Condition, a) Total depression score * Condition; b) Depression group * Condition	Ethnicity

Model 3a & 3b	Spreading of Alternatives	Age * Value certainty * Choice confidence, a) Total depression score * Value certainty * Choice confidence; b) Depression group * Value certainty * Choice confidence	Ethnicity
Model 4a & 4b	Choice confidence	Age * Choice type, a) Total depression score * Choice type; b) Depression group * Choice type	Sex, Ethnicity
Model 5a & 5b	Value certainty (part 1 only)	Age * Choice type, a) Total depression score * Choice type; b) Depression group * Choice type	
Model 6a & 6b	Value certainty	Age * Rating * Condition, a) Total depression score * Rating * Condition; b)	

		Depression group * Rating * Condition	
	Linear regressions		
	Dependent variable	**Predictors of interest**	**Covariates**
Model 7a & 7b	SoA difference (mean SoA-RPR minus mean SoA-RcRP)	Age * Condition, a) Total depression score * Condition; b) Depression group * Condition	

Note. Mixed-effects models use trial-level data. Linear regressions use participant-level data. Models 1,2 and 6 use reciprocal age. Models 3–5 use the second-degree polynomial term of age. Condition is a binary variable describing whether activities were in RPR (rating, preference choice, rating) or RcRP (rating, colour choice, rating, preference choice) conditions. Choice type is a binary variable describing whether trials were preference or colour choices. Depression group is a binary variable describing whether participants were below or above the clinical cut-off (12) on the Mood and Feelings Questionnaire – Short Form. Value difference refers to the difference in initial ratings between the chosen minus the unchosen choice option. Value certainty refers to the mean of both activities' value certainty ratings in each choice pair. * indicates interactions for individual terms and all lower-level interactions and main effects.

Table 5.2 **Model equations: Switching task.**

	Linear regressions		
	Dependent variable	**Fixed effects of interest**	**Covariates**
Model 1a	Time on self-preference quiz	Age, depression score	Time on colour quiz
Model 1b	Time on other-preference quiz	Age, depression score	Time on colour quiz, sex, number in room
Model 1c	Time on colour quiz	Age, depression score	Ethnicity
Model 2a	Enjoyment ratings of self-preference quiz	Age, depression score	Enjoyment of x-game, ethnicity
Model 2b	Enjoyment ratings of other-preference quiz	Age, depression score	Enjoyment of x-game
Model 2c	Enjoyment of colour quiz	Age, depression score	Enjoyment of x-game

Note. Mixed-effects models use trial-level data. Linear regressions use participant-level data. Model 1a, 1b & 1c used reciprocal age. Models 2a & 2b used exponential age and Model 2c used cubic age.

Justification of sample size

An *a priori* power analysis was conducted using G*Power (Faul et al., 2007) to determine the minimum sample size required to test the prediction that there would be an age-related decrease in the SoA-RPR but not in SoA-RcRP. The required sample size to achieve 80% power for detecting a small effect size (f^2) of .05 (equivalent to r=.25), at a significance criterion of α=.05, was N=196 for a linear multiple regression with two tested predictors (age and age-squared) and six control predictors (number of participants in the room, gender, ethnicity, income, non-verbal reasoning score, SoA-RcRP). I recruited 242 participants to allow for ~20% exclusions and the final sample size for analysis was N=214 participants.

Results

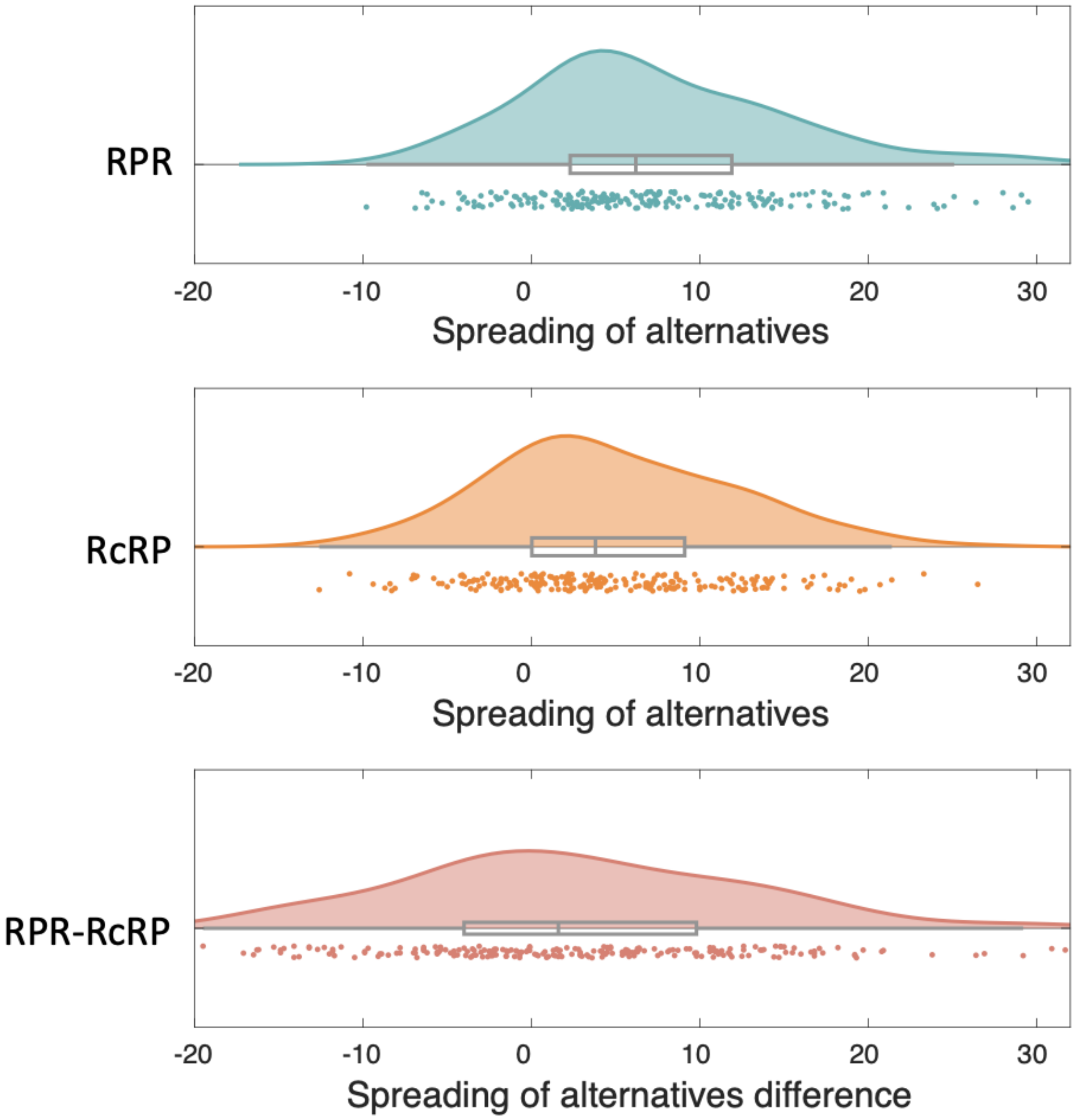
Choice-induced preference change

As expected, participants demonstrated a significant mean SoA, which was evident both when preference choices occurred between the ratings (RPR: $t(213)=13.59$, $p<.001$; $dz=.93$; M ± sd = 7.26 ± 7.81; Fig. 5.2, top panel) and when they occurred after the ratings (RcRP: $t(213)=9.72$, $p<.001$, $dz=.66$; M ± sd = 4.74 ± 7.13; Fig. 5.2, middle panel).

Importantly, the SoA was significantly greater when preference choices occurred between the ratings (RPR) compared with when they occurred after both ratings had been completed (RcRP) (SoA-difference: $t(213)=3.68$, $p<.001$, $dz=.20$; M ± sd = 2.52 ± 12.63; Fig. 5.2, bottom panel). Therefore, a significant effect of SoA remained after controlling for (within-subjects) the expected effect from the statistical artefact.

SoA in both conditions appeared to be symmetrical for chosen and unchosen activities. There was no significant difference in the extent to which participants uprated chosen activities and downrated unchosen activities in both conditions, as shown by a non-significant interaction between condition (RPR versus RcRP) and item type (chosen versus unchosen) on the difference in ratings across rating 1 and rating 2 ($\chi 2=2.44$, $\beta=1.12$, $SE=.72$, $t=1.56$, $p=.118$; RPR, chosen: mean change=3.72, sd=16.03; RPR, unchosen: mean change=-3.54, sd=18.41; RcRP, chosen: mean change=1.90, sd=15.34; RcRP, unchosen: mean change=-2.84, sd=16.37).

Figure 5.2 **Spreading of Alternatives**



Note. Raincloud plots distribution of participants' mean spreading of alternatives (SoA) for the ratings, preference choices, ratings condition (RPR; top panel), the ratings, colour choices, ratings, preference choices condition (RcRP; middle panel) and difference (RPR-

RcRP, bottom panel). Points show mean spreading of alternatives for each individual participant. Boxes in grey represent interquartile range and median. SoA difference represents mean SoA-RPR minus SoA-RcRP.

Choice features associated with Spreading of Alternatives

According to the value refinement account, SoA should be strongest for choice pairs that required greater deliberation (low value difference, low value certainty) but were resolved in a confident choice. I therefore assessed the association between SoA and three measures: 1) the difference in initial ratings between two alternatives (chosen minus unchosen); 2) average value certainty across the two alternatives; and 3) choice confidence. First, I used linear mixed-effects models with value difference, value certainty and choice confidence, as well as their interactions with choice condition (RPR versus RcRP) as fixed effects (models 1a&b; Fig. 5.3). I then tested the interaction between value certainty and choice confidence and its impact on SoA (models 3a&b; Fig. 5.4), to test the hypothesis that SoA results from the resolution of value uncertainty during choice deliberation.

There was a significant negative association between value difference and SoA ($\chi 2$=312.37, β=.36, SE=.02, t=17.67, p<.001), such that, as expected, choosing between activities with a smaller difference in initial value ratings was associated with a larger SoA. The negative association between value difference and SoA-RPR was significantly stronger than the association with SoA-RcRP (value-difference-by-choice-condition interaction: $\chi 2$=3.91, p=.048; $slope_{RPR}$=-.42, SE=.02, p<.001, $slope_{RcRP}$=-.36, SE=.02, p<.001, $contrast_{RPR\text{-}RcRP}$=-.06, SE=.03, p=.048).

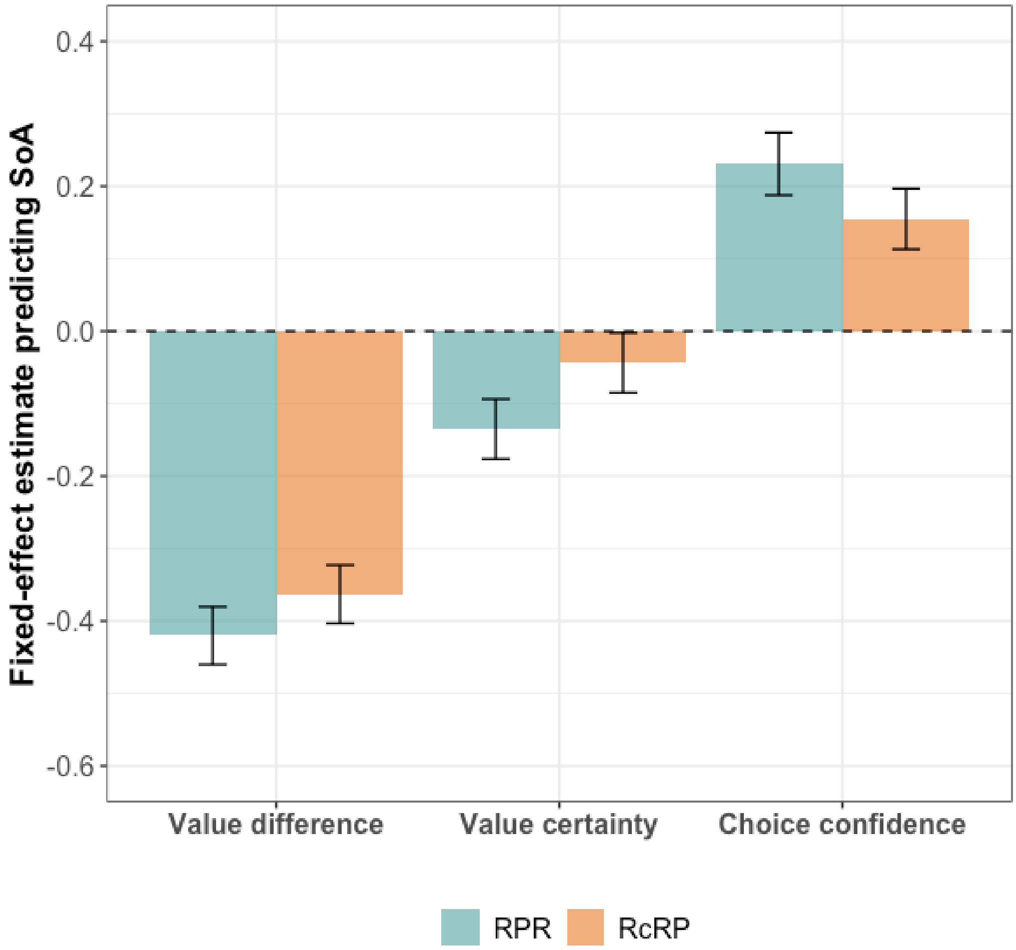
There was also a significant negative association between value certainty and SoA ($\chi 2$=4.22, β=-.04, SE=.03, t=-2.05, p=.040), such that, as expected, choosing between activities with a lower initial mean value certainty was associated with a larger SoA. Again, this association was significantly stronger for SoA-RPR compared with SoA-RcRP ($\chi 2$=9.93, p=.002;

$\text{slope}_{\text{RPR}}$=-.14, *SE*=.02, *p*<.001, $\text{slope}_{\text{RcRP}}$=-.04, *SE*=.02, *p*=.040, $\text{contrast}_{\text{RPR-RcRP}}$=.09, *SE*=.03, *p*=.002).

Finally, there was a significant positive association between choice confidence and SoA ($\chi 2$=52.74, β=.16, *SE*=.02, *t*=7.26, *p*<.001), such that, as expected, SoA was larger when participants reached a confident choice. The association between choice confidence and SoA-RPR was significantly stronger than with SoA-RcRP ($\chi 2$=6.32, *p*=.012; $\text{slope}_{\text{RPR}}$=.23, *SE*=.02, *p*<.001, $\text{slope}_{\text{RcRP}}$=.16, *SE*=.02, *p*<.001, $\text{contrast}_{\text{RPR-RcRP}}$=.08, *SE*=.03, *p*=.012).

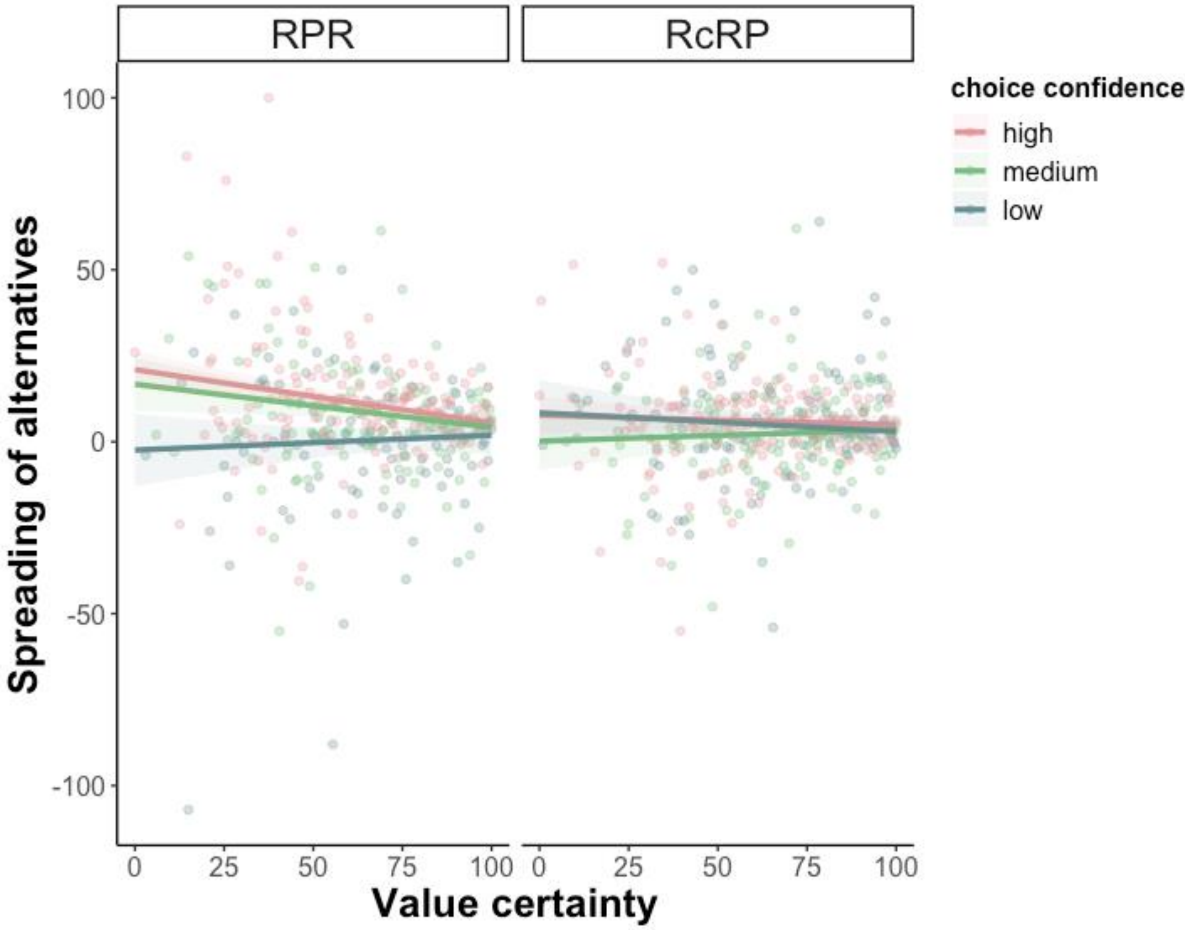
When analysing the interaction between value certainty and choice confidence, as predicted by the value refinement account I found that participants showed a stronger SoA on trials where they were initially less certain about their value ratings but nonetheless still reached a confident choice. This interaction was specific to the RPR condition, with a significant interaction between choice condition (RPR versus RcRP), mean value certainty and choice confidence (Figure 5.4; $\chi 2$=6.01, *p*=.014). For post-hoc comparisons and visualisation, I stratified choice confidence scores into three bands: low (<=33), medium (34–66) and high (>=67). This allowed me to compare the impact of mean value certainty on SoA across levels of choice confidence, and between conditions. In the RcRP condition, there were no significant effects of value certainty on SoA for any level of choice confidence ($\text{slope}_{\text{RcRP(low)}}$=-.05, *SE*=.06, *p*=.393; $\text{slope}_{\text{RcRP(medium)}}$=.03, *SE*=.05, *p*=.536; $\text{slope}_{\text{RcRP(high)}}$=-.03, *SE*=.03, *p*=.351). For the RPR condition, lower mean value certainty was associated with higher SoA, only when participants reached a high or medium level of confidence in their choice, but not for low-confidence choices ($\text{slope}_{\text{RPR(low)}}$=.04, *SE*=.06, *p*=.542; $\text{slope}_{\text{RPR(medium)}}$=-.12, *SE*=.04, *p*=.010; $\text{slope}_{\text{RPR(high)}}$=-.14, *SE*=.03, *p*<.001). The association between value certainty and SoA when confidence was medium or high was significantly stronger in the RPR compared with the RcRP condition ($contrast_{RPR\text{-}RcRP(medium)}$=-.14, *SE*=.07, *p*=.027; $contrast_{RPR\text{-}RcRP(high)}$=-.12, *SE*=.04, *p*=.003). There was no difference between conditions for low-confidence choices ($contrast_{RPR\text{-}RcRP(medium)}$=.09, *SE*=.09, *p*=.304).

Figure 5.3 **Choice features associated with spreading of alternatives**



Note. Y-axis shows fixed effect estimates in a model predicting trial-level spreading of alternatives (SoA). RPR refers to the ratings, preference choices, ratings condition. RcRP refers to the ratings, colour choices, ratings, preference choices condition. Error bars show standard error.

Figure 5.4 **Evidence of value refinement in spreading of alternatives**



Note. Mean value certainty was negatively associated with SoA-RPR (spreading of alternatives; ratings, preference choices, ratings) at medium- and high-confidence levels but not low confidence levels. The associations between mean value certainty and SoA-RcRP (spreading of alternatives; ratings, colour choices, ratings, preference choices) were not significant at any level of choice confidence. Lines represent model estimates. Points represent mean SoA at each unique level of mean value certainty and choice confidence. Shaded area represents 95% confidence intervals.

Changes in value certainty and rating-choice associations across timepoints

On average, value certainty increased between rating 1 and rating 2 ($\chi 2$=7.00, β=.96, *SE*=.36, *t*=2.65, *p*=.008). Value certainty increased significantly more when participants completed preference choices between ratings (RPR) than when they completed colour choices between ratings (RcRP) (rating-by-condition interaction: $\chi 2$=4.42, *p*=.036; $\text{contrast}_{\text{RPR-RcRP(rating1)}}$=.12, *SE*=.51, *p*=.817, $\text{contrast}_{\text{RPR-RcRP(rating2)}}$=1.19, *SE*=.51, *p*=.019). Analysed separately, both conditions alone showed a significant increase in value certainty between rating 1 and rating 2 ($\text{contrast}_{\text{rating2-rating1(RPR)}}$=2.03, *SE*=.36, *p*<.001, $\text{contrast}_{\text{rating2-rating1(RcRP)}}$=.96, *SE*=.36, *p*=.008).

As expected, in the RPR condition, a model with value difference of the second set of ratings (value rating left item minus value rating right item) predicting choice (choose left) was a better fit than when using the first set of ratings to calculate the value difference (BIC rating 2=2229.9; BIC rating 1=2630.2).

According to the statistical artefact account, when predicting preference choices that occur after both ratings, models using rating 1 value difference and rating 2 value difference should fit the data equally as well. However, in contrast to this I found that the second rating value difference was a better predictor of choice than the first rating value difference in the RcRP condition (BIC rating 2=2366.0, BIC rating 1=2642.4).

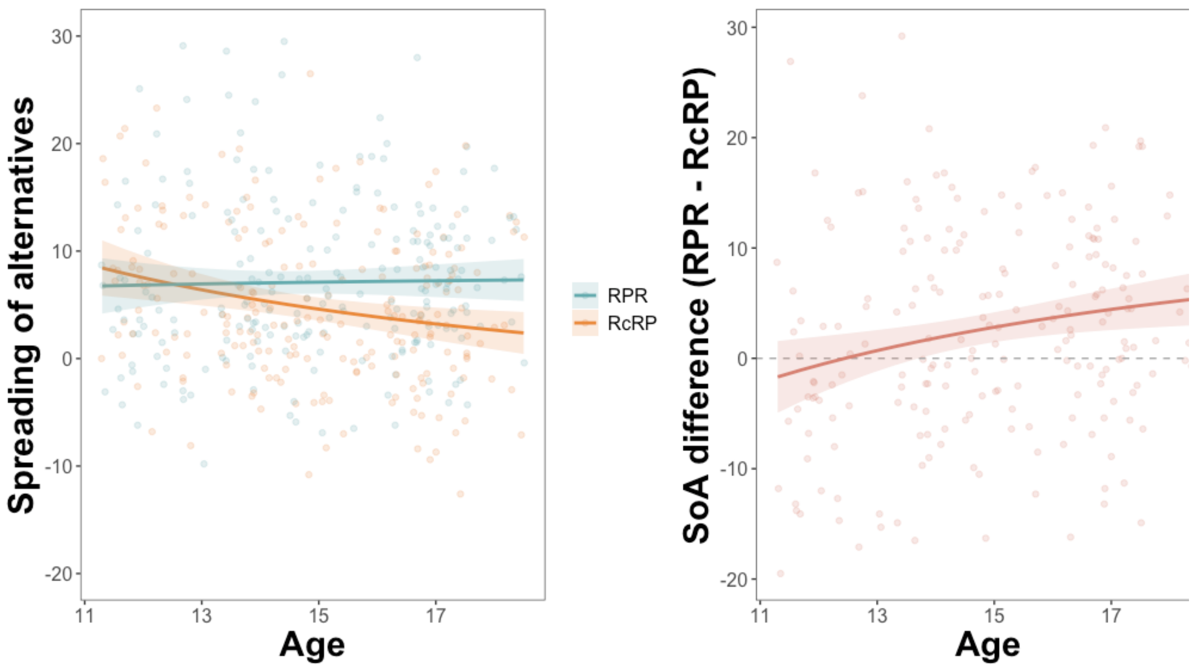
Taken together with the robust SoA-RcRP, these results raise the possibility that some value refinement may have occurred in the RcRP condition, possibly during ratings or during colour choices. This is consistent with previous work showing that value refinement occurs during tasks other than preference choices (Lee & Hollyoak, 2021).

Developmental changes in choice-induced preference change

Spreading of alternatives across age. There was a significant age-by-condition-interaction (RPR vs RcRP) for SoA ($\chi 2$=6.35, p=.012; Fig. 5.5, left panel). Surprisingly, and in contrast to my hypothesis, post-hoc contrasts demonstrated a significant relationship between the reciprocal of age and SoA-RcRP but not SoA-RPR ($slope_{RPR}$=-.74, SE=2.69, p=.784; $slope_{RcRP}$=8.00, SE=2.69, p=.003; $contrast_{RPR-RcRP}$=-8.74, SE=3.5, p=.012).

When inspecting the SoA-difference score (RPR minus RcRP; model 7), I found a significant association with reciprocal age (β=-206.25, SE=72.92, t=-2.83, p=.005; Fig. 5.5, left panel).

Figure 5.5 **Age-related change in spreading of alternatives**



Note. Left panel: Spreading of alternatives (SoA) for activities in the Ratings, Preference choices, Ratings (RPR) condition and activities in the Ratings, Colour choices, Ratings, Preference choices (RcRP) condition. Right panel: SoA-RPR minus SoA-RcRP age-related change in SoA after accounting for spreading of alternatives in the control condition (driven at least in part by the statistical artefact). Lines show model estimates. Shaded areas show confidence intervals.

Investigating age-related preference change after colour choices. There are a number of possible explanations for the age-related difference in SoA-RcRP. Here I provide additional analyses to investigate four possibilities, that age-related change in SoA-RcRP is due to: 1) age-related increase in attention to instructions; 2) age-related increase in variability of ratings and thus value difference in choice pairs; 3) age-related difference in the effect of colour choices for eliciting value refinement; 4) age-related difference in overall noise in ratings.

First, I assessed possible age-related differences in attention to instructions. The observed inflated SoA-RcRP in younger participants may have been due to younger participants ignoring the instructions and answering colour choice questions as if they were preference choices, which would result in value refinement. To test this, I calculated the number of trials on which the chosen item during the colour choice matched the chosen item when the same pair of activities was presented in the final preference choices. There was no age-related change in the number of matching choices between colour choices and preference choices after ratings (reciprocal age: β=-5.66, SE=15.09, t=-.38, p=.708), arguing against this explanation of the observed effects.

The statistical artefact relies on the pairing of closely rated activities. Thus, I next checked if there were any age-related associations in value difference between paired activities. If younger participants showed less variation in their value ratings than older participants, the pairing algorithm could yield more pairs with a small value difference, eliciting a stronger SoA (Fig. 5.3). I thus investigated age-related differences in variability (standard deviation) of ratings and also tested whether value differences in pairs of activities across all choices were lower for younger participants. I did not find any age-related differences in variability of value (reciprocal age: β=36.79, *SE*=42.73, *t*=.86, *p*=.390) or any age-related difference in value difference between choice pairs (reciprocal age: $\chi2$=.02, *p*=.892; β=.61, *SE*=4.46, *t*=.14, *p*=.892), arguing against this explanation of the observed effects.

A third possible explanation for the age-related difference in SoA-RcRP is that making colour choices elicited value refinement, especially in the younger participants. Younger adolescents may be particularly motivated to consider their preferences, or may find it more difficult to switch tasks between preference-based tasks (i.e. ratings and preference choices) to colour choices. To test this explanation, I ran a number of analyses. First, I selected colour choice trials on which participants selected options that were in conflict with their selection in the later preference choices, and tested whether younger adolescents were slower to make these incongruent choices. I constructed a linear mixed-effects model with reaction time (RT) as an outcome and tested the interaction between reciprocal age and match condition (whether or not the colour choice matched the preference choice). There was no evidence that younger participants were slower on choice-incongruent trials (age-by-match interaction: $\chi2$=.02, *p*=.902). I also conducted a similar analysis, testing whether on trials with longer RTs during colour choices (which may provide sufficient time to additionally consider their preferences), participants showed a larger SoA-RcRP and whether this effect was modulated by reciprocal age. I did not observe evidence for either of these patterns (RT main effect: $\chi2$=.19, *p*=660; RT-by-age interaction: $\chi2$=.08, *p*=.776). Next, I tested whether younger participants' RTs in colour choices were more highly related to the preference characteristics of the choice pairs (e.g. value difference, certainty and choice confidence of the equivalent preference choice). Again, I did not find evidence of such an effect (interaction between value difference and reciprocal age: $\chi 2$=.03, p=.866; value certainty and reciprocal age: $\chi 2$=.04, p=.837; choice confidence (part 4) and reciprocal age: $\chi 2$=.02, p=.893).

I then examined the change in certainty between rating 1 and rating 2, reasoning that if younger participants exhibited a larger SoA-RcRP due to value refinement during colour choices, they should update their value certainty more after making colour choices, relative to older participants. I tested this prediction with a linear mixed effects model with certainty rating as the dependent measure, including the interaction between age (reciprocal), rating (1 or 2) and condition. I also tested whether younger participants displayed a larger speeding of value ratings between rating 1 and 2 after colour choices than older participants, by replacing the outcome variable with value-rating RT. I did not find evidence of age-related change in the extent to which colour choices led to increased value certainty (age-by-rating-by-condition interaction: $\chi 2$=2.56, p=.110) or speeding of value ratings (age-by-rating-by-condition interaction: $\chi 2$=1.18, p=.277).

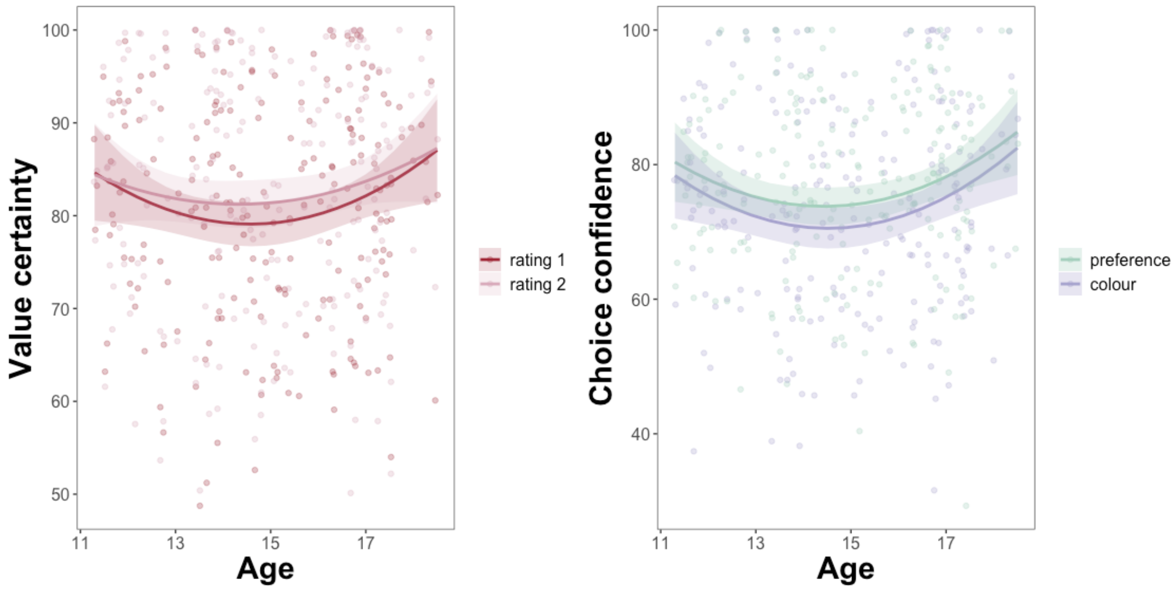
A final possible explanation of the age-related differences in SoA is that younger participants have greater noise in their initial value ratings. Greater noise should lead to a larger SoA due to the statistical artefact (Fig. 5.3). Indeed, the correlation between initial and second ratings showed an age-related increase (reciprocal age: β=-2.54, t=-2.89, p=.004). I also observed a pattern that younger participants' preference choices were noisier; in a logistic regression, age modulated the effect of value difference (rating 1; left item minus right item) on choice (choose left), which would be expected when initial ratings are noisier, albeit the interaction narrowly missed statistical significance ($\chi2$=3.82, p=.051). If younger participants have a larger SoA due to the statistical artefact as a consequence of noisier ratings, this would affect both RcRP and RPR conditions. Since SoA-RPR does not show the same age-related decrease as SoA-RcRP, this implies that younger participants show (relatively) less SoA due to value refinement. This is also evident when inspecting the SoA difference score, which accounts for the component of SoA driven by noise in the ratings (Fig. 5.5, right panel).

Value certainty and choice confidence across age. I next tested how confidence (both value certainty and choice confidence) vary with age. I initially included age as an additional predictor along with value certainty and choice confidence in the model with SoA as the outcome. Through this, I could test whether age modulated the interaction between value certainty and choice confidence in the RPR condition. This tests whether younger participants' show a stronger SoA when value certainty is resolved through choice. However, the four-way interaction between age (reciprocal), value certainty, choice confidence and choice condition was non-significant ($\chi2$=.21, p=.647).

Both value certainty and choice confidence exhibited a U-shaped association with age (Fig. 5.6). Accordingly, there was a significant association between the quadratic (but not linear) component of age and initial value certainty ($\chi2$=5.33, p=.069; linear: β=42.60, SE=76.12, t=.56, p=.576; quadratic: β=170.06, SE=76.32, t=2.23, p=.027; see Fig. 5.6, left panel). The age-related change in the extent to which value certainty was updated after choice in either condition was non-significant (age-by-rating interaction: $\chi2$=3.25, p=.071; age-by-rating-by-condition interaction: $\chi2$=2.56, p=.120).

There was a significant association between the quadratic (but not linear) component of age and choice confidence ($\chi 2$=7.58, p=.023; linear: β=65.84, SE=84.95, t=.78, p=.439; quadratic: β=215.35, SE=81.91, t=2.63, p=.009; see Fig. 5.6, right panel). There was no significant interaction between the linear or quadratic components of age and choice condition ($\chi 2$=.23, p=.889; linear: β=10.83, SE=54.29, t=.20, p=.842; quadratic: β=24.47, SE=53.98, t=-.45, p=.650). There were also significant main effects of the covariates sex and ethnicity on choice confidence. Females were less confident than males ($\chi 2$=4.25, p=.039). Latin American and Arab participants were more confident than all other groups and there were no differences between the other ethnic groups ($\chi 2$=9.62, p=.047).

Figure 5.6 **Age-related differences in initial value certainty and choice confidence**



Note. Left panel: Initial value certainty. Points represent individual participants' mean initial value certainty ratings in the first ratings. Right panel: Choice confidence. Points represent individual participants' mean confidence ratings in the second and final part of the task. Lines show model estimates. Shaded areas show confidence intervals.

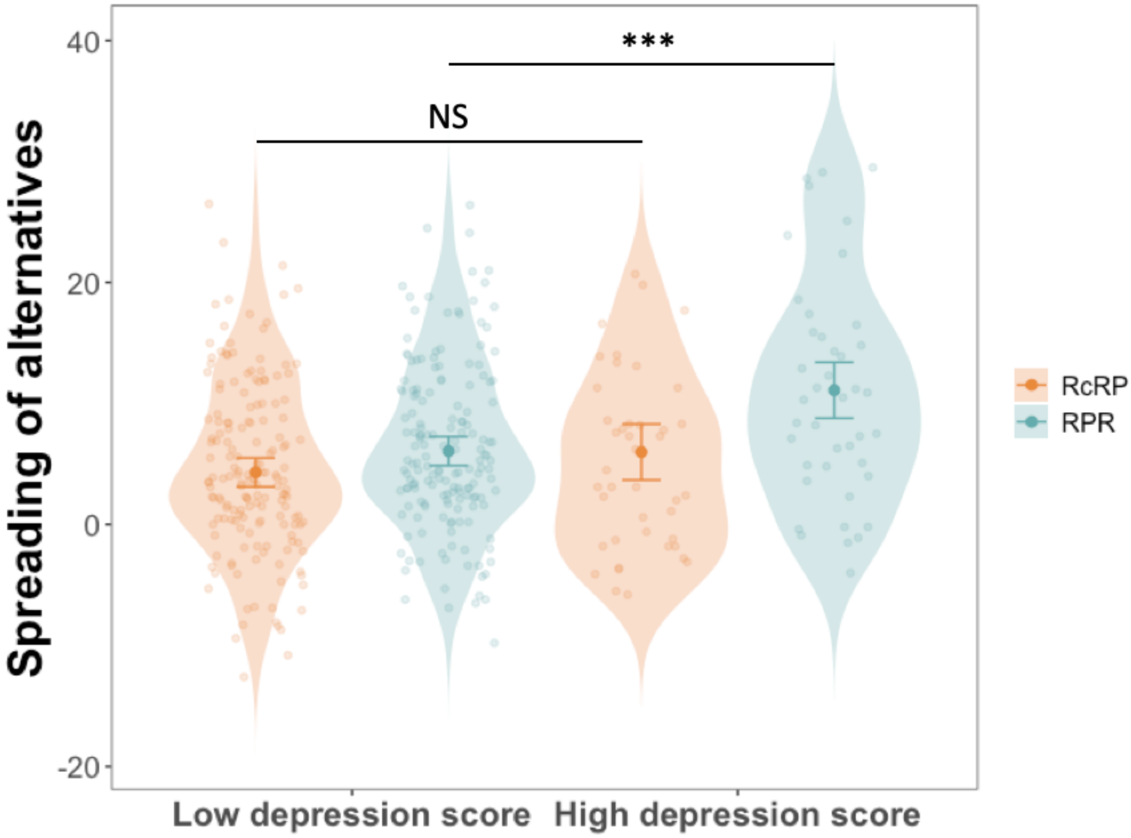
Depressive symptoms and choice-induced preference change

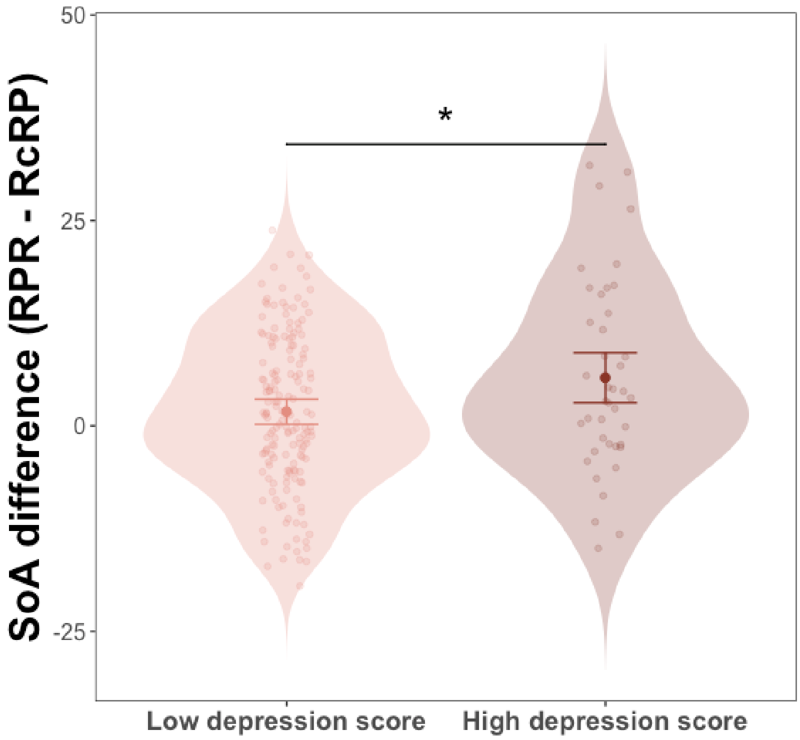
Scores on the MFQ-SF covered the entire range (0–26, M=7.80, SD=5.77). There were 54 participants who scored 12 or above, indicating possible depression. I report all associations with depressive symptoms continuously and by depression group (<12, >=12).

Spreading of alternatives and depressive symptoms. The interaction between depressive symptom score and condition (RPR versus RcRP) predicting SoA was non-significant ($\chi2$=.69, p=.405; $\text{contrast}_{\text{RPR-RcRP}}$=.03, SE=.03, p=.405). When isolating the effect of SoA from value refinement (i.e. mean SoA-RPR minus mean SoA-RcRP), there was no significant association between depressive symptoms and SoA (β=.63, SE=.72, t=.88, p=.380).

When using categorical depression, the interaction between condition (RPR versus RcRP) and depression group predicting SoA narrowly missed significance ($\chi2$=3.83, p=.057; Fig. 5.7, top panel). Post-hoc comparisons demonstrated that participants who met the clinical cut-off for depression showed a stronger SoA-RPR than those below the cut-off ($\text{contrast}_{\text{Depressed-Non-depressed(RPR)}}$=.23, SE=.06, p<.001). There was no difference between the groups on SoA-RcRP ($\text{contrast}_{\text{Depressed-Non-depressed(RcRP)}}$=.08, SE=.06, p=.207). Additionally, and contrary to my hypothesis, participants who scored above the clinical cut-off had a higher SoA-difference than those scoring below the cut-off (β=3.81, SE=1.67, t=2.28, p=.023; Fig. 5.7, bottom panel).

Figure 5.7 **Depression-related differences in spreading of alternatives**





Note. Low depression score indicates participants scoring below 12 on the Mood and Feelings Questionnaire – Short Form. High depression score indicates participants scoring 12 or above. Points indicate participant means. RPR – ratings, preference choices, ratings. RcRP – ratings, colour choices, ratings, preference choices. Error bars show 95% confidence intervals. * p<.05, *** p<.001, NS non-significant.

Value ratings, value certainty and choice confidence and depressive symptoms. To further investigate depression-related differences in SoA, I assessed whether depressive symptoms modulated the interaction between value certainty and choice confidence on SoA-RPR. There was a significant four-way interaction between choice condition (RPR versus RcRP), choice confidence, value certainty and depressive symptom score, as well as between these three predictors and depression group in the categorical analysis (depressive symptom score: $\chi 2$=10.91, p<.001; depression group: $\chi 2$=10.36, p=.001). I again used stratified confidence scores (low, medium, high) to investigate post-hoc comparisons. In the RPR condition, the modulation of the relationship between value certainty and SoA by choice confidence was greater in the depressed group. This was most evident in high- and low-confident choice trials ($\text{contrast}_{\text{Depressed-Non-depressed(RPR,low)}}$=.47, SE=.14, p<.001; $\text{contrast}_{\text{Depressed-Non-depressed(RPR,medium)=}}$.16, SE=.11, p=.123; $\text{contrast}_{\text{Depressed-Non-depressed(RPR,high)}}$=.13, SE=.06, p=.046). In other words, depressive symptom score was associated with a greater SoA after value refinement (value uncertainty resolving in a confident choice). Neither groups showed an association between value certainty and SoA-RcRP at any level of confidence

There was also a significant association between depressive symptoms and initial value certainty, whereby participants with greater depressive symptoms reported less certainty about their value judgements ($\chi 2$=6.72, β=-2.25, SE=.87, t=-2.59, p=.010; Fig. 5.8, left panel). Depressive symptoms were also associated with lower value certainty updating across both conditions (rating-by-depressive-symptom-score interaction: $\chi 2$=4.28, p=.039) but this was not modulated by condition (rating-by-condition-by-depressive-symptom-score interaction: $\chi 2$=.07, p=.795).

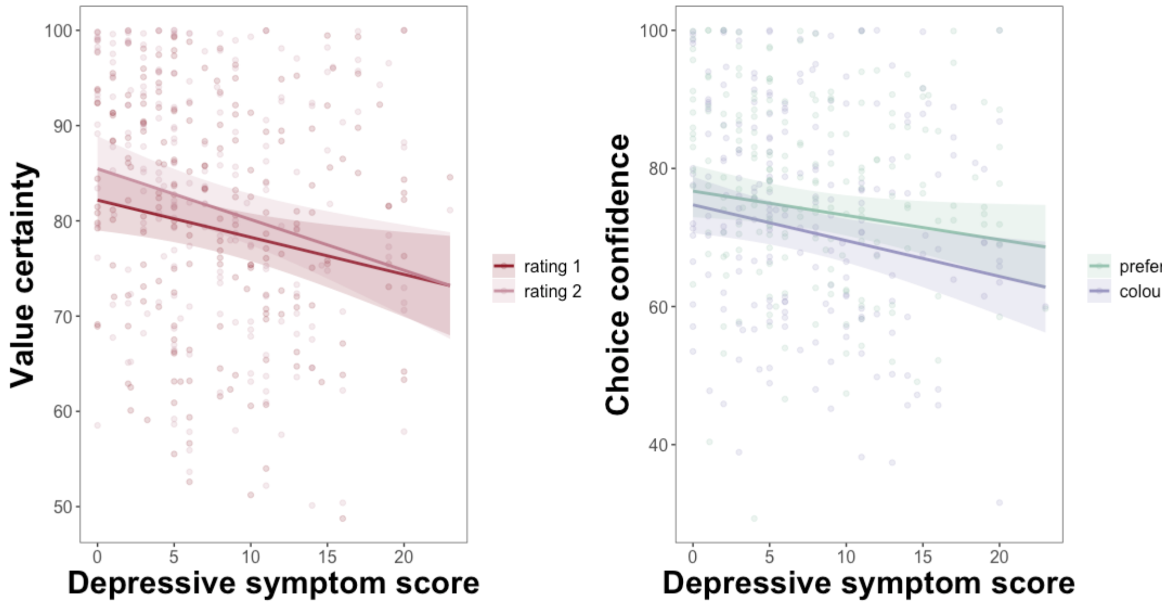
Participants with greater depressive symptoms also reported lower choice confidence overall (main effect of depressive symptoms: $\chi2$=7.30, β=-2.99, *SE*=1.10, *t*=-2.70, *p*=.007; Fig. 5.8, right panel). The interaction between depressive symptoms and choice type (preference versus colour) was non-significant ($\chi2$=1.73, *p*=.188), suggesting that depression symptoms were associated with a global reduction in choice confidence.

In summary, depressive symptoms were associated with greater updating of value ratings (SoA) when value refinement had occurred during preference choices (low initial value certainty resolved in a high confidence choice). Depressive symptoms were also associated with lower initial value certainty, lower updating of value certainty across all activities and lower preference and colour choice confidence. Together these factors may explain the greater SoA I observed in more depressed participants, which was contrary to my hypothesis.

When considering depression categorically (MFQ-SF cut-off score of 12), the above associations with value certainty, certainty updating, and preference/colour choice confidence were no longer apparent (value certainty: $\chi2$=1.34, *p*=.247; overall value certainty updating: $\chi2$=2.21, *p*=.137; choice confidence: $\chi2$=1.54, *p*=.214).

Finally, I tested whether depression was associated with lower reported enjoyment of the activities, but neither depressive symptoms nor depression group were associated with value ratings overall (symptoms: β=-.07, *SE*=.13, *t*=-.52, *p*=.603; group: β=.90, *SE*=1.69, *t*=.53, *p*=.596).

Figure 5.8 **Depression-related differences in value certainty and choice confidence**



Note. Depressive symptoms were associated with lower initial value certainty and lower choice confidence (across part two and part four, in preference and colour choices).

Switching task

SART (X game) performance. One-hundred and thirty-six participants had 100% accuracy in the SART. Participants' performance (d', hits minus false alarms) was on average 98.57% (sd = 2.90%). There was no significant association between d' and age (β = .001, SE = .05, p = .824). Therefore, reward rate in the SART was similar across the age range.

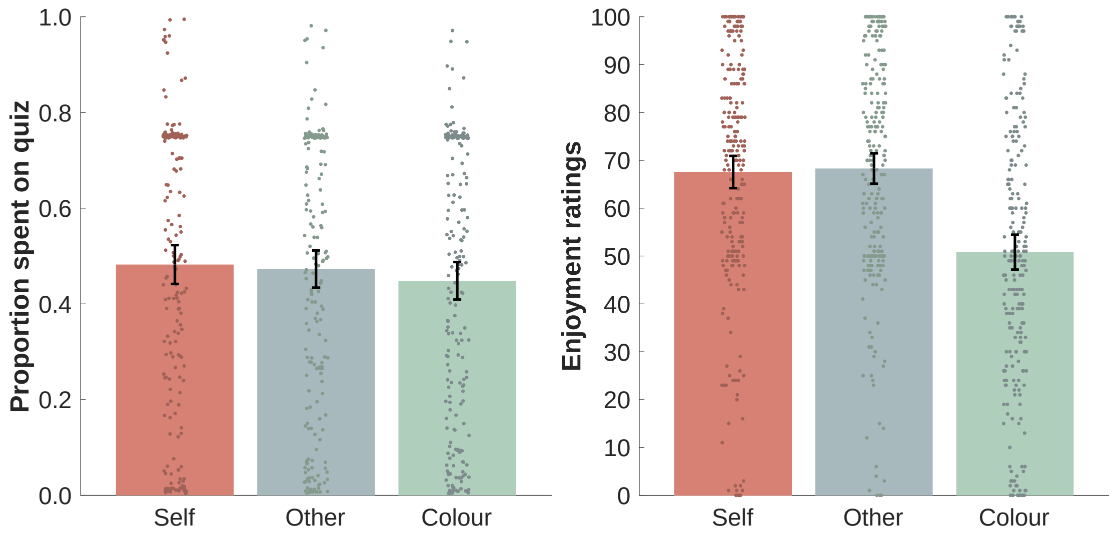
Other person choice. Participants chose to answer about their mother (n=134), father (n = 35), brother (n = 14), sister (n=11), aunt (n=9), cousin (n=6), grandma (n=2) and family friend (n=2).

Proportion of time spent on each quiz type. Participants were willing to spend on average 48.22% (sd = 30.17%) of their allocated time (i.e. forgo 48.22 pence of their reward) on the self-quiz task, 47.28% (sd = 28.83%) of their time on the other-quiz task and 44.81% (sd = 29.11%) of their time on the colour-quiz task. There were no significant differences in time spent between quiz types. See Fig. 5.9, left panel.

Age was not significantly associated with time spent on the self- or the other-quiz types when controlling for time on the colour-quiz task (self: $\beta = 1.46$, $SE = 2.75$, $t = .53$, $p = .595$; other: $\beta < .001$, $SE < .001$, $t = .73$, $p = .470$).

There was no association between depressive symptom scores and proportion of time spent on any of the quiz types (self: $\beta = -.03$, SE = .02, t = -1.85, p = .066; other: $\beta = -.009$, SE = .002, t = -.54, p = .589; colour: $\beta = -.02$, SE = .02, t = -.76, p = .453).

Figure 5.9 **Switching task behaviour**



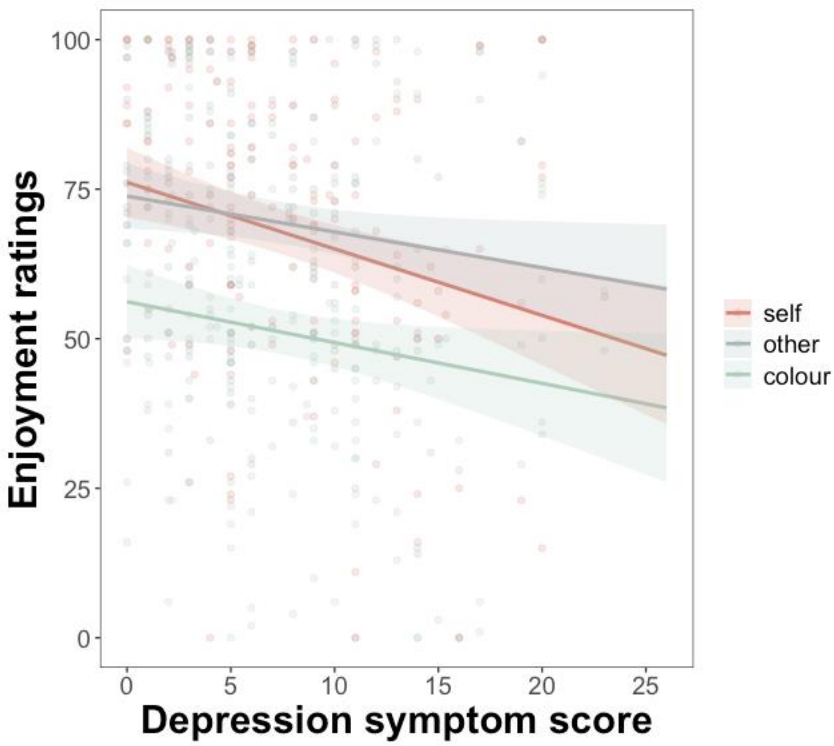
Note. Left panel shows proportion of the 4-minute block spent on each quiz type. Right panel shows participants' subjective enjoyment ratings of each quiz type. Dots represent individual participants and error bars show 95% confidence intervals.

Subjective enjoyment ratings. Participants rated the self-quiz type as more enjoyable than the colour-quiz ($t(233) = 7.72$, $p < .001$, $dz = .50$), and the other- quiz as more enjoyable than the colour-quiz ($t(233) = 8.76$, $p < .001$, $dz = .57$). There was no significant difference in subjective enjoyment of the self-quiz compared with the other-quiz ($t(233) = -.44$, $p = .658$, $dz = .03$). See Fig. 5.9, right panel.

Age was not significantly associated with subjective enjoyment scores of any quiz type (self: β < .001, $SE < .001$, $t = .67$, $p = .501$; other: β < .001, $SE < .001$, $t = -.78$, $p = .436$; colour: $\beta < -.001$, $SE < .001$, $t = -.23$, $p = .819$).

Greater depressive symptoms scores were associated with lower subjective liking of the self-, other- and colour-quizzes (self: β = -.24, *SE* = .07, *t* = -3.56, *p* < .001; other: β = -.14, *SE* = .07, *t* = -2.13, *p* = .035; colour: β = -.14, *SE* = .07, *t* = -2.09, *p* = .038; Fig. 5.10).

Figure 5.10 **Subjective enjoyment and depressive symptoms**



Note. Depressive symptom score represents total score on the MFQ-SF. Lines represent model estimates and shaded areas represent 95% confidence intervals. Dots represent individual participants.

Associations between subjective enjoyment and time spent. When controlling for subjective liking scores of the SART, subjective liking of the self- and colour-quiz was not associated with proportion of time spent on the respective quiz (self: $\beta = -.18$, SE $=.21$, $t = -.83$, $p = .493$; colour: $\beta = -.005$, SE $= .003$, $t = -1.58$, $p = .256$). Subjective liking of the other-quiz was significantly associated with time spent on the other-quiz ($\beta = -.38$, SE $= .06$, $t = -6.88$, $p = .021$). This relationship was not modulated by age.

Associations with Spreading of Alternatives. SoA-difference (mean SoA-RPR minus mean SoA-RcRP) was not associated with time spent on the self-quiz ($\beta < .001$, SE $< .001$, $t = -.40$, $p = .691$).

SoA-difference was significantly negatively associated with subjective enjoyment of the self-quiz ($\beta = -.02$, SE $= .007$, $t = -2.75$, $p = .007$). This appeared to be driven by a positive association with SoA-RcRP ($\beta = .02$, SE $= .01$, $t = 2.70$, $p = .008$) and no significant association with SoA-RPR ($\beta = -.004$, SE $= .009$, $t = -.49$, $p = .625$).

SoA-RcRP was not associated with enjoyment ratings of the colour or other-preferences quiz (other-preferences: $\beta = .01$, SE $= .01$, $t = .72$, $p = 0.475$; colour: $\beta = -.01$, SE $= .01$ $t = -1.32$, $p = 0.187$)

Switching task motivation. Participants were given the option to provide free text feedback on why they spent time on each of the quiz tasks in the X game, revealing the multiple motivations for completing the quiz tasks.

Two hundred and five participants responded to the motivation question on the self-preferences quiz. Of these, 39 participants mentioned text about being motivated to complete the task because it was fun, interesting or enjoyable; for example: “it was fun”, “it was interesting to reflect on hypothetical questions and my own opinions and reasonings”, “It was fun seeing the pictures and picturing myself in the situations”. Fifty participants included text about the quiz helping them to learn about or gain certainty in their preferences; for example: “so I could learn more about myself”, “It was an eye opener on how much I appreciated one thing over another when I never had much thought of these things”, “I enjoy learning more about myself and who I am as a person”. Eleven participants mentioned self-disclosure or expression: for example, “because I like to share stuff about my preferences”, “because I like spreading my opinion”, “form of expression without the need of talking to others”.

Two hundred and twenty-three participants responded to the motivation question about the other-preferences quiz. Forty participants mentioned the quiz being fun, interesting or enjoyable; for example: “makes me happy to know that I can answer questions on someone I love”, “enjoyed thinking about what my dad would answer”, “it was interesting to think in the perspective of another person”. Forty-three participants mentioned being motivated to complete the other quiz as a test of their knowledge of the other person or to find out how much they knew about the other person; for example: “I wanted to see how much I knew about the person”, “to make sure I know my mum well”, “to see if I really know the other person”, “because it showed me that I know more than usual without knowing it”. Nine participants mentioned being motivated to complete the task as a way of comparing their own and their chosen person’s preferences; for example: “I wanted to really think about what they would want and if we are similar in which and what ways”, “to see if we are similar”, “I thought it would be interesting to compare the answers I chose with the options she would really choose”. Eleven participants mentioned being motivated to complete the quiz because they believed it would help them learn about the other person: for example: “so I find out more about them”, “to get to know my dad’s preferences more”, “because I wanted to see what choices that they would choose”.

Two-hundred and twenty-five participants responded to the motivation question about the colour quiz. Forty participants mentioned the quiz being fun, interesting or enjoyable; for example: “the pictures given were very aesthetic”, “it was satisfying”, “it was interesting to see what colours appealed to me”. Twenty-five participants mentioned using the quiz to test or improve their knowledge, eyesight or colour vision; for example: “I was testing how well my brain knew colours”, “I can improve my eye skills”, “wanted to challenge my brain”, “wanted to test myself about how I can determine colours better since I want to learn more about colours”.

There were also examples of demand characteristics and misunderstandings of the task. For example, twenty-six responses mentioned believing that completing the quiz would help research; for example: “the whole point was to study about me so the X game wouldn’t really help with achieving the purpose of this”, “so I can help your research”, “to support this study”. There were also 45 responses across all quiz types that showed clear misunderstandings of the task; for example: “I didn’t realise until the final round that I couldn’t do the X game later.”, “I thought it was essential”, “I forgot I could switch games”, “I thought I would get more money than the x game”.

Results after excluding for misunderstanding. I reanalysed the data excluding participants who indicated in written feedback that they misunderstood the Switching task (n=21 excluded). All results remained the same, except that SoA-difference was no longer associated with time spent on the self-quiz ($\beta = -.01$, $SE = .01$, $p = .141$).

Discussion

I investigated a potential mechanism of self-concept development, namely adolescents' ability to use choice to update and refine their preferences. Adolescents displayed a substantial CIPC, updating their value estimates and value certainty after preference choices. Importantly, the observed SoA occurred over and above that expected from a statistical artefact account (Chen & Risen, 2010). I replicated previous findings supporting a value refinement account of CIPC. Specifically, larger SoAs occurred when participants could confidently choose between closely-rated activities that they were initially less certain about, providing further evidence that preference change occurs as a result of choice deliberation rather than cognitive dissonance. The same pattern of results was not observed when preference choices did not occur until after all ratings had been made.

Once accounting for SoA resulting from statistical artefact, I demonstrated an age-related increase in adolescents' ability to update and refine their preferences through choice. Participants under the age of 14 showed very little value refinement, which increased across the older age range. Reported value certainty and choice confidence showed an age-related U-shaped association, with younger participants and older participants reporting higher certainty in value judgements and choices (both preference and colour) than participants in the middle of the age range. Participants scoring above the clinical cut-off on the depression scale had a larger SoA due to value refinement, with larger updates in their value ratings when resolving initial uncertainty during choice. Despite this, participants with greater depressive symptoms reported lower initial value certainty, which remained low during the second ratings, and lower choice confidence across all choices (although this pattern was not evident when considering depression categorically). I discuss the implications of my results for adolescent self-concept development, in light of increased mental health risks.

Adolescence is marked by a growing sense of independence and autonomy. Across adolescence, young people are often given more opportunities to be unsupervised by adults, which expands their decision-making space. This is frequently accompanied by increased novelty seeking, risky decision making and resistance to authority. These behaviours allow adolescents to learn about themselves and their environment in the face of uncertainty. However, this period is also characterized by prolonged maturation of decision-making abilities, including the ability to reflect on choices (Moses-Payne et al., 2021; Weil et al., 2018) and to resist influence from others (Roebers, 2002; Roebers & Howie, 2003; Schwarz & Roebers, 2006). These findings motivated my interest in understanding age-related differences in adolescents' ability to learn about their preferences through choice.

Overall, I found that adolescents across the ages of 11–18 were able to use choice to refine their preferences, updating their value estimates and increasing value certainty after making preference choices. The addition of value certainty and choice confidence ratings to the task design allowed me to replicate previous work supporting the value refinement explanation of SoA. I showed that SoA was stronger when participants were asked to make decisions between activities they were initially less certain about but, after deliberation, managed to confidently choose between. This pattern of result supports the notion that SoA reflects, at least in part, a process of choice deliberation and value refinement.

Interestingly, I found that younger adolescents showed a greater SoA for activities in the control (RcRP) condition, where preference choices were not made until all ratings were complete. This SoA-RcRP is expected to arise from Chen and Risen's (2010) 'statistical artefact' account, which rests on key behavioural and methodological features of the free-choice paradigm. It proposes that participants' value ratings are noisy and that preference choices at least partially reflect participants' true preferences. In order to maximize the potential for SoA, the task design required that closely-rated activities be paired. However, this also increases the likelihood that the statistical artefact will arise if the ratings are drawn from the edges of their true value distributions (i.e. if they are especially impacted by noise). I concur that this is a convincing explanation of SoA-RcRP, but it is still interesting to understand the cognitive influences on the SoA in the absence of preference choice. I suggest that the age-related change in SoA-RcRP demonstrated here could reflect younger adolescents' greater uncertainty about their own preference ratings, increasing noise in their ratings. Therefore, the consequent heightened SoA-RcRP in early adolescents is likely reflective of processes that relate to the statistical artefact, but which themselves may derive from important developmental changes that are occurring during this period. As this is expected to affect both SoA-RcRP and SoA-RPR, I next aimed to isolate the effect of SoA due to true value refinement.

This study employed a design that allowed me to isolate the SoA effect resulting from value refinement. Specifically, I calculated within-participant difference scores by subtracting each subject's SoA in the absence of preference choices between ratings (SoA-RcRP) from their SoA due to preference choices (SoA-RPR). This enabled me to investigate the isolated SoA effect specifically resulting from value refinement, which I found to follow an asymptotic age curve. The results indicated an increase in this effect across the earlier age range in the current study (around 11–14 years), which then plateaued towards the older age range. Interestingly, previous research has suggested that the ability to accurately reflect upon choices exhibits a similar developmental pattern, potentially emerging in early adolescence (Fandakova et al., 2021; Moses-Payne et al., 2021). I speculate that this lesser ability to reflect on choices, coupled with increased uncertainty about the value of different activities and the decision-making process, may have hindered younger participants' ability to learn during choice deliberation and adjust their values accordingly. Future work should measure both of these cognitive faculties and examine their potential relationship.

I also conducted supplementary analyses to explore alternative possible explanations of the observed age-related changes in SoA. One possibility is that value refinement can occur not only during preference-based choices but also during deliberation over non-preference-based choices, e.g. the colour choices included here (D. G. Lee & Holyoak, 2021). The findings provided some evidence supporting this possibility. Specifically, in the RcRP condition, where no value refinement is expected to occur (according to a statistical artefact account), I observed an increase in value certainty between ratings and found that second value ratings were a better predictor of choice than initial ratings. This raises the possibility that simply being faced with choice alternatives (even without preference-based instructions) may stimulate some value refinement. Therefore, it is possible that value refinement also occurred during the colour choices and that the age-related change in SoA-RcRP was due in part to age-related decline in value refinement during colour choices. However, I tested a number of predictions derived from this hypothesis but did not find any evidence to support it. Nevertheless, future studies may consider including an additional control condition in which colour choices are removed, to more accurately assess SoA resulting from the statistical artefact. If value refinement indeed occurred in the RcRP condition, one would expect that removing colour choices from the control condition would make the age-related changes in SoA difference scores even more pronounced.

Interestingly, I found that the noise present in the value ratings of younger adolescents was not reflected in their subjective reports of uncertainty. Instead, younger and older adolescents reported the greatest certainty in their initial value ratings. The same U-shaped developmental pattern was also observed for confidence judgements in both preference and colour choices. In contrast, there was no age-related difference in value updating on trials where initial value certainty was resolved in a highly confident choice. The motivation to seek information and resolve uncertainty in our preferences through choice, depends on the ability to accurately estimate and monitor uncertainty (Gottlieb et al., 2013). If younger adolescents were overly certain about their value estimates, their motivation to resolve uncertainty through choice may have been reduced, which could explain why they showed lower value refinement. This is consistent with previous research suggesting that late childhood and early adolescence is associated with inflated metacognitive judgements of performance, as shown in Chapter 3 (Moses-Payne et al., 2021; van Loon et al., 2017; Was & Al-Harthy, 2018). However, results are mixed, with different paradigms producing different developmental patterns of metacognitive judgements (Brackmann et al., 2019; Fandakova et al., 2021). This is likely influenced by differences in the underlying performance itself (Fleming & Lau, 2014), reducing the ability to decouple metacognitive judgements from task performance. This limitation is shared by the current study, as there is no "ground truth" or accuracy in value-based decisions. Therefore, the results point to an interesting avenue for future research: to assess developmental changes in adolescents' ability to monitor uncertainty and generate strategies for reducing uncertainty. However, this may be best assessed in non-value-based decisions, where changes in task performance can be matched across age and decoupled from metacognitive performance.

It is well established that adolescence is a period of increased risk for the onset of mental health conditions (Kessler, Angermeyer, et al., 2007; Solmi et al., 2022). One potential area for intervention is the development of self-concept, as negative self-appraisals and increased uncertainty in self-concept have been linked to the development of depressive symptoms (Mullarkey et al., 2019a; Orth et al., 2008a; Rieger et al., 2016b). By understanding how adolescents construct their sense of self, we may be able to help young people develop a positive and stable self-concept during this time of change. I found that adolescent depressive symptoms were associated with lower certainty in values, lower updating of value certainty after choice and lower choice confidence, which aligns with previous findings that depressive symptoms are negatively associated with confidence in adults (Rouault, Seow, et al., 2018); albeit this pattern was not observed when treating depression categorically.

Interestingly, participants scoring over the MFQ-SF cut-off for depression had an apparently intact SoA due to value refinement. In fact, categorically defined depression was associated with greater SoA on trials where initial value uncertainty was resolved in a confident choice. These findings may indicate that depressive symptoms are associated with decreased subjective reports of certainty and confidence in the presence of an intact value-refinement mechanism. In other words, depressed adolescents were able to use choice to reassess their value estimates but nonetheless remained less confident in their choices and less certain about their values in spite of this. This might suggest a potentially fruitful avenue for intervention in depression in adolescence: targeting adolescents' feelings of certainty and confidence in their decisions rather than targeting decision making *per se*. It would also be interesting to investigate whether these alterations in confidence are related to a reduction in seeking real-world autonomous choices, given that depressed adolescents may not experience the same (rewarding) reduction in uncertainty from independent choice as healthy adolescents. However, longitudinal designs are needed to ascertain whether these differences in certainty and confidence are a risk-factor for depression or simply reflect the presence of symptoms.

I attempted to measure adolescent motivation to refine value estimates through choice using a novel task. During the task, adolescents were able to switch between a tedious task to gain monetary reward and a quiz task where no monetary reward was available. Through qualitative participant feedback, I discovered that the task did not effectively target and measure adolescent motivation to complete preference choices. Instead, adolescents completed all three quiz tasks (self-preference, other-preference and colour choices) for a variety of reasons. Perhaps for this reason, I did not observe the expected age-related changes or relationships between tasks when investigating time spent (reward forgone) on the quiz tasks. In fact, the time spent measure was only associated with subjective liking scores of the other-preference task, indicating the complexity of motivations to spend time of the quiz tasks and the myriad of reasons underlying the liking scores. If redesigning the task, I would aim to improve clarity of the instructions by using a split screen to display the two tasks so that the opportunity to switch was more evident.

When investigating subjective liking scores of each quiz type, there were no age-related changes in subjective liking scores for any quiz type. Depressive symptoms were related to decreased enjoyment of all quiz types, perhaps reflecting anhedonic symptoms that impede motivation and enjoyment of activities. Interestingly, subjective liking of the self-preference quiz was related to increased SoA-RcRP. This may provide some support for the alternative hypothesis that increased SoA-RcRP was due to motivation for value refinement even during colour choices.

In order to better elucidate whether value refinement is rewarding, particularly for adolescents, new tasks will need to be developed. One option is to measure mood during the FCP, for example with a mood rating after each choice, so that the impact of value refinement on mood could be assessed at a trial-by-trial level. Another option could be introducing a willingness to pay measure during the FCP. Using these paradigms, one could also investigate the impact of value uncertainty and choice confidence on mood and motivation. I would hypothesise that adolescents would be willing to pay to complete self-preference choices when they were particularly uncertain about the items they would be asked to choose between, and that they may show enhanced mood when they were able to reach a confident choice between uncertain options.

In summary, I found that independent decision-making in adolescence may be an important means of refining and developing a self-concept. This ability emerges during adolescence, with younger adolescents potentially less able to use choice to refine their value estimates. Depressive symptoms were associated with greater refinement of values during choice deliberation. Despite this, more depressed adolescents remained less certain about their preferences and were less confident in their choices. Future work should build on these results to further our understanding of the processes involved in self-concept formation in adolescence, including how these processes are influenced by depressive symptoms, which would enable more effective support to promote a healthy self-concept during this critical development stage.

Chapter 6

The role of real-world exploration in adolescents’ early high school and university experiences

Abstract

During adolescence, individuals gain increasing autonomy and independence. Adolescence is also a period of heightened exploratory behaviour, but little is known about the potential adaptive benefits of exploration. Here I investigated real-world exploration during adolescence and its association with feelings of autonomy, affect and making new social contacts. Further I assessed how adolescents' ability to adjust to new social norms and fluctuations in their mental health symptoms modulated these associations. I assessed adolescent participants during a formative transitional period: the first three months of a new high school in New York City (13–15-year-olds) or the first three months of New York University (17–19-year-olds). Participants' ability to adjust to new social norms was measured using an experimental task at the start of the school year. For the next three months, participants provided continuous GPS data, affect ratings and reported on their feelings of autonomy and new social contacts. Participants reported increased positive affect, decreased negative affect and gained more new social contacts on days when they roamed their physical environment more (shared their time across many unique locations). The relationship between roaming and feelings of autonomy was modulated by age, in that younger adolescents reported feeling less autonomy on days where they explored more, whereas older adolescents reported similar levels of autonomy on high and low roaming days. Feelings of autonomy were strongly related to increased positive and decreased negative affect, and university students were particularly negatively affected by lack of autonomy. Finally, when participants reported high anxiety symptom, this disrupted the relationship between exploration and positive affect. I did not find that the relationship between

roaming and mood or roaming and new social contacts was modulated by participants' ability to adjust to new social norms in the task-based measure. These results suggest that exploration may facilitate social networking and be reinforced through positive affect, and may indicate increasing importance of autonomy across adolescence.

Introduction

Exploration is heightened in adolescence and is thought to facilitate the transition to independence (Ciranka & van den Bos, 2021; Lloyd et al., 2021; Saragosa-Harris et al., 2022). In this chapter, I investigated how exploration is reinforced and promotes independence in adolescence, through its associations with positive affect, feelings of autonomy and social network building. I captured adolescents at a moment of transition – the start of a new school year – during which young people are required to navigate highly novel physical and social spaces. I compared university-aged adolescents (17–19-year-olds) during the first three months of New York University (NYU) to high-school-aged adolescents (13–15-year-olds) in New York City during the first three months attending a new high school. I also explored individual differences that may facilitate or interrupt these processes, including the ability to adapt behaviour to new social norms and mental health symptoms.

The transition to a new school is a formative event that poses numerous challenges for adolescents. They are required to navigate unfamiliar physical spaces, such as a new route to school, new buildings and a new class schedule. Additionally, their established social networks are disrupted, and hierarchies change as they shift from being the oldest at their previous school to the youngest at their new school. In some cases, students must entirely rebuild their social network. This occurs at a time when adolescents are highly sensitive to peer feedback and are striving to assert their independence. The purpose of this study was to investigate whether physical exploration is associated with adjustment to this highly novel experience, as assessed through measures of social networks and affect.

Exploration promotes knowledge acquisition and is partly driven by uncertainty (Gottlieb et al., 2013; Lloyd et al., 2021; Somerville et al., 2017). In naturalistic contexts, the inclination to explore the physical environment increases throughout adolescence, peaking around the age of legal independence (18–21 years; Saragosa-Harris et al., 2022). On laboratory tasks, adolescents typically display greater levels of exploratory behaviour compared to adults (Christakou et al., 2013; Jepma et al., 2020; Lloyd et al., 2021). It has been proposed that amplified exploration, including risk-taking tendencies, observed during adolescence arises from an imbalance between heightened sensitivity to rewards and a still-developing capacity for response inhibition or cognitive control (Ernst et al., 2005; Luna et al., 2013; Steinberg et al., 2008a, 2008b). As adolescents develop, their exploration strategies tend to become more sophisticated and goal directed (Dubois et al., 2022; Somerville et al., 2017). Notably, the heightened propensity for exploration during adolescence is not unique to humans (Romer et al., 2017; Maslowsky et al., 2019), suggesting that it serves a functional role in normative developmental processes. Indeed, exploration affords the opportunity to have meaningful novel experiences, helping adolescents learn about themselves and the world (Ciranka & van den Bos, 2021; Lloyd et al., 2021). In this way, heightened exploration may facilitate the transition to adult independence, allowing adolescents to learn about their environment and establish social connections beyond their immediate family ties.

Some have argued that exploration is reinforced through the intrinsically rewarding properties of novelty (Heller et al., 2020; Kakade & Dayan, 2002; Krebs et al., 2009; Wittmann et al., 2008). Much prior work investigating the association between exploration, novelty and positive affect has been laboratory-based (Bardo et al., 1996; Bunzeck et al., 2012; Houillon et al., 2013). However, recent work has investigated experiential diversity and positive affect in the real world, utilising geolocation data from participants' mobile phones to calculate "roaming entropy", which indexes the predictability of an individual's location over time (Freund et al., 2013). In these studies, roaming entropy has been found to relate to both greater novelty (calculated by counting the number of locations that have not yet been recorded during the tracking period) and positive affect reported via survey (Heller et al., 2020; Saragosa-Harris et al., 2022).

There is evidence that feelings of autonomy are important drivers of learning and wellbeing across development (Carlson, 2023; Ryan & Deci, 2011). Here, I propose that feelings of autonomy may modulate the association between exploration and positive affect. Take, for example, a delivery driver who visits multiple locations in a day. Presumably, the rewarding nature of exploration in this scenario is constrained due to the lack of autonomy the driver holds over their daily activities. As autonomy increases during adolescence, the manner in which young people experience exploration may change. In this way, older adolescents may derive more benefits from exploration, as their explorative behaviour is more frequently self-directed. In Chapter 5, I suggested that older adolescents were better able to learn about their own preferences through making choices, and proposed that this uncertainty reduction would be rewarding. Therefore, in the current chapter, I had the following hypotheses: feelings of autonomy would be associated with more positive affect; older adolescents would feel greater autonomy over their real-world exploration and older adolescents would show a stronger association between autonomy and affect.

Exploration may also facilitate independence through social network building (Saragosa-Harris et al., 2022). Establishing one's own social network is an important step towards adult independence and there is evidence that forging quality friendships promotes adolescent wellbeing and self-esteem (Raboteg-Saric & Sakic, 2014; Tomova et al., 2021). In a previous study (Saragosa-Harris et al., 2022), adults' and adolescents' average roaming entropy was associated with increased social network size, using a one-off measurement. This provides some initial evidence that exploration may be associated with diversity of social experience. Here I investigated whether daily roaming was associated with the daily addition of new social contacts during the first three months of a new school or university.

Previous work has suggested that greater rates of development in brain regions implicated in social cognition were associated with stronger increases in friendship quality (Becht et al., 2021b). Adolescents are particularly sensitive to social group dynamics and are often keen to conform to prescribed norms (Pinho et al., 2021; Tomova et al., 2021). This can foster certain undesirable behavioural tendencies, such as increased dangerous risk taking in the presence of peers (Chein et al., 2011; Gardner & Steinberg, 2005; Leather, 2009), but also promotes pro-social behaviour (Ahmed et al., 2020; Chierchia et al., 2020b). I predicted that young people would be better able to build social contacts if they are highly in tune with and responsive to changing social norms. To test this, I adapted an interactive task from a previous study in adults (U. Hertz, 2021), in which participants competed with other players to collect stars. I measured the extent to which participants adjusted their competitive behaviour (zapping other players) to align with the normative behaviour modelled by the other players (implemented by an algorithm). I hypothesised that the relationship between exploration and social network building would be stronger for young people who are able to rapidly adapt their behaviour to new, changing social norms.

Adolescence is a period of vulnerability for the onset of mental health conditions (Kessler et al., 2007; Solmi et al., 2022). The transition to a new school may be particularly stressful, as adolescents must leave behind familiar social networks and established friendships, meet new academic demands and navigate unfamiliar spaces. To explore this relationship, I additionally tracked the development of symptoms of mental health problems, specifically depression and anxiety, across the first three months of the transition period. Previous work has shown that such symptoms are associated with lower real-world exploration. For example, geolocation features extracted from mobile phone sensor data showed that lower roaming was associated with greater depressive symptoms (Saeb et al., 2015, 2016). I therefore predicted that greater depressive/anxious symptoms would be associated with decreased exploration in the current study. As I have discussed, increased exploration, especially in novel environments, may have various benefits for young people. However, little is known about how the presence of symptoms affects these associations. I hypothesised that adolescents with worse mental health would not gain the same benefits, in new social contacts or positive affect, from increased exploration as healthy adolescents with good mental health.

In order to test the above hypotheses, I recruited university students and high schoolers to participate in the study for the first three months of their new university or school. Participants were asked to allow the tracking of their geolocation for the entire study period and to report their affect, social contact gain and feelings of autonomy every 48 hours. Participants reported depression and anxiety symptoms every two weeks. In an initial session, participants completed a computerized task that measured their ability to adapt to new social norms, alongside a social anxiety scale.

Methods

Participants and recruitment

I recruited two groups of participants: adolescents entering their first year at a new high school in New York City and adolescents entering their first year at NYU. Participants were recruited within their first two weeks of starting at their new school through a laboratory participant database and public flyers at NYU and in New York City.

For participants under 18 years of age, parental consent and child assent was obtained. Participants over 18 were able to consent to participate themselves.

In total, 68 participants completed the initial session. There were 27 high school students (13 females, 1 other gender identity; age 13.67–15.29 at initial session, M = 14.32) and 42 NYU students (31 females, 2 other gender identities; age 17.82–19.13 at initial session, M = 18.44). One participant (female, aged 18.79) was excluded immediately after the initial session as they were unable to download the GPS location app. Four participants were excluded from analysis for having fewer than 10 days of GPS location data (as implemented in previous work, Saragosa-Harris et al., 2022). Excluded participants were one male and two female high schoolers and one female university student. The final sample included 24 high school students (11 females, 1 other gender identity; age 13.67– 14.99 at initial session, M = 14.28) and 40 NYU students (29 female, 2 other gender identities; age 17.82–19.13 at initial session, M = 18.43).

Participants were reimbursed with a $15 Amazon voucher after completing the initial session. Participants remained enrolled in the study for 12 weeks after their initial session. If participants responded to at least 60% of the text surveys and kept the GPS location app active for at least 90% of the study period, they received a $25 Amazon voucher after 6 weeks and an additional $25 Amazon voucher after 12 weeks.

All recruitment, consent forms, and data collection were completed in accordance with the requirements of the New York University Institutional Review Board who provided ethical approval for the study. I pre-registered the study design and hypotheses on OSF (https://osf.io/7autk/files/osfstorage/6397822b4cc86c0707116ee4).

Given the constraints of needing to recruit all participants within the first two weeks of their new school or university, I conducted a sensitivity power analysis, rather than an *a priori* power analysis, using G*Power. I conducted this for the between-subjects analysis of age group on roaming entropy, which included three covariates: two race covariates (indicating racial group and a binary variable indicating Hispanic origin) and gender. This analysis indicated that the smallest effect that I could have detected given 80% power and the number of participants, was $f^2 = .13$ (equivalent to Pearson's coefficient $r = .33$).

Procedure

Participants were invited to participate in the study remotely via a laboratory recruitment platform. When signing up within the platform participants provided the following baseline information: date of birth, race, gender, number of people living at home, fluency in English, colour blindness, presence of a learning disability, neurodevelopmental disorder or psychiatric disorder (lifetime).

Participants were enrolled in the study for 12 weeks. They completed an initial session online at home, including the Grid World task and mental health questionnaires (see further details below). Their GPS was continuously recorded for 12 weeks. Every 48 hours participants were asked to complete an affect survey, a social network gain item and an autonomy item. Every two weeks, participants were also asked to complete mental health questionnaires and a location-based affect survey.

Initial session. Participants were asked to complete the session on their own (without parental supervision or interference from others) and to ensure that they were in a suitable environment (e.g., quiet, minimal distractions, with electronic devices stored and unnecessary programs closed).

The initial session lasted approximately 45 minutes and included the Grid World game (Hertz, 2021) and mental health questionnaires: Mood and Feelings questionnaire Short form (MFQ-SF; Angold & Costello, 1987; Sharp, Goodyer & Croudace, 2006), Generalized Anxiety Disorder 7-item scale (GAD-7; Spitzer, Kroenke, Williams & Lowe, 2006) and the Liebowitz Social Anxiety Scale for Children (Masia-Wamer et al., 2003). During the initial session, participants were also asked to set up the GPS location app (FollowMee) and to provide their mobile number for EMA purposes.

Grid World Social Learning Game. The Grid World task was implemented using Javascript, HTML and CSS and hosted on Pavlovia. Task design and code was adapted from Hertz (2021), see Fig. 6.1 for task interface.

Participants played Grid World with three other virtual players, represented as coloured squares on a 10-by-10 grid. Participants took turns with the other players, in a fixed order. On each turn, participants chose to either move one place in one of four directions (horizontally/vertically) or to 'zap' another player by emitting a pink ray in one of the four directions. When a player was zapped, they were moved to a 'time out zone' and were not able to make any moves for three turns. Stars could appear in any place on the grid and players could collect stars by moving their player to the same place on the grid.

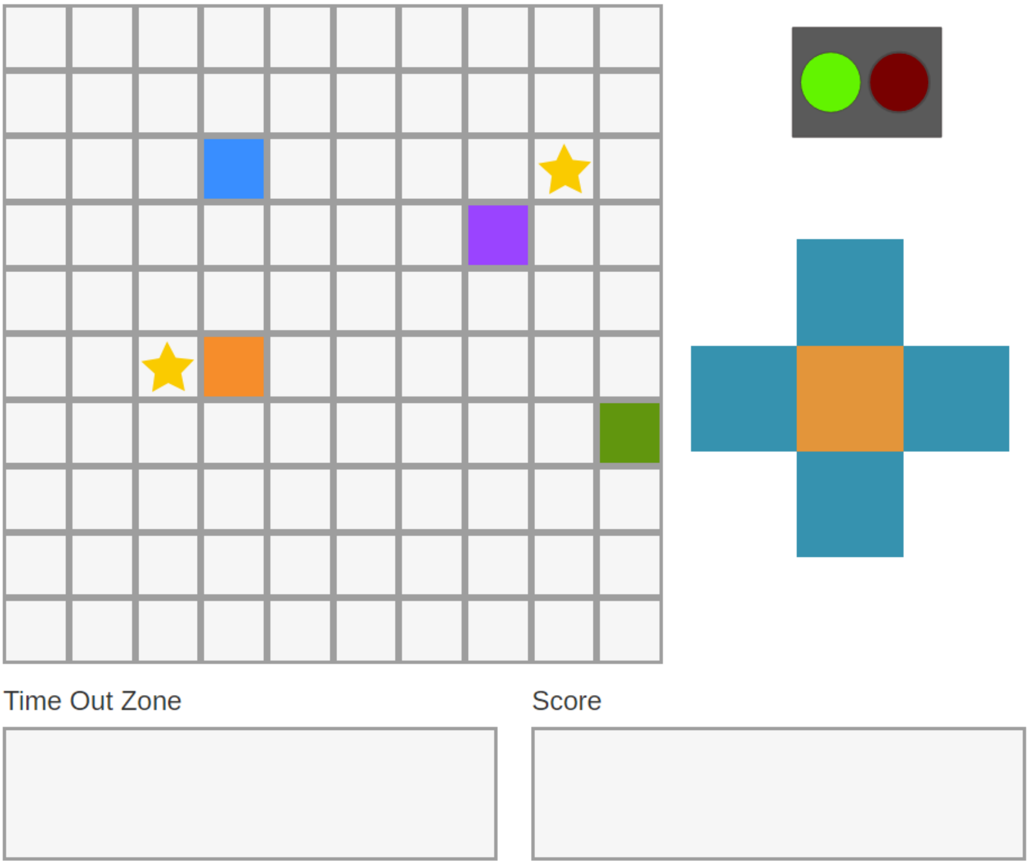
Once collected, participants' stars appeared in their score zone. On each round, in which all players took a turn, a new star appeared with a 75% probability and uncollected stars could disappear.

Participants completed Grid World in 3 blocks. The blocks differed according to the social norm algorithm governing the virtual players' behaviour. In each block, all three virtual players were governed by the same social norm algorithm.

In each block, the virtual players began their turn by looking for the closest star, and if they were the player closest to the star they would move towards it. The blocks differed in the virtual players' behaviour when another player was closest to the star. In the first block, players' behaviour was governed by a 'harm-omission' norm. This meant that virtual players were 'polite': if there was another player who was closer to the star, virtual players would move away from other players without zapping. In the harm-omission blocks, virtual players never zapped other players. In the second block, players' behaviour was governed by a 'harm-action' norm. This meant that virtual players were 'competitive': if there was another player who was closest to the star, and that player was within the line of a potential zap ray, then the player would always zap that player. In the final block, virtual players were again governed by a harm-omission or polite norm, as in the first block. This allowed me to investigate participants' adaptation to the social norm across both transitions: from a polite to a competitive norm, and from a competitive to a polite norm.

Adaptation to the social norm was measured by recording participants' zapping behaviour. Highly adaptive participants will not zap in the harm-omission norm condition, and will always zap when there is an opportunity to do so in the harm-action norm condition.

Figure 6.1 **Social learning task interface**



Note. Task interface created by Hertz (2021). Participants played as the blue player, represented by a blue square, against three other players in each round, each also represented as a square of another colour. At the onset of each round, the colour of the other players' squares changed to represent a new group of players. At the beginning of each trial, a green light (upper right) was displayed to the participant to indicate that it was their turn to play. Participants could either move one space on the grid by clicking on a blue button (middle right) or zap another player by clicking the orange button (middle right). When other players were taking their turn, a red light was displayed (upper right). If a player was zapped, their square was moved to the Time Out Zone for three turns. Once collected by the participant, stars were displayed in the Score box.

Ongoing assessments. For the 12 weeks following the initial session, participants' GPS locations were recorded continuously via the FollowMee app.

Once every 48 hours, at a randomly selected time between 9am–5pm participants were prompted via text message to respond to the following measures: an affect survey, social network gain item and an autonomy item.

Once every two weeks, participants were also asked to respond to the MFQ-SF, the GAD-7 and to answer a single location-related affect question.

Affect survey. The affect survey consisted of ten items (five positive, five negative items) from the Positive and Negative Affect Schedule (PANAS; Watson, Clark & Tellegen,1988): *happy, excited, determined, relaxed, attentive, nervous, jittery, upset, irritable, sluggish*. Participants were asked to rate each item on a scale from 0 – "Not at all" to 100 – "Intensely". The marker value was hidden to avoid anchoring effects.

Social network gain. Participants were asked to respond by entering a number to the prompt "*In the past 48 hours, how many people have you met face-to-face and also* *stored contact details for in your phone?*". Further information was given "*You may have stored their phone number, followed them on Instagram or added them on Snapchat. We'd like you to count anyone who you have met and saved contact details for, on any platform. You can count people who you have met before, as long as you added their contact details for the first time in the past 48 hours.*"

Autonomy. Participants were asked "*Think about all the activities you did in the last 24 hours. How many of the activities were your choice versus something you had to do or something that someone else chose for you?*". Participants were asked to rate this on a scale from 0 – "None of the activities I did were my choice" and 100 – "All of the activities I did were my choice". The marker value was hidden.

Location-based affect. Participants were asked "*In the past two weeks, how much have you enjoyed 1. Being at home; 2. Being out of the house.*" Participants responded on a five-point Likert scale from "Did not enjoy at all" to "Very much enjoyed it".

Statistical Analysis

Geolocation postprocessing and metrics

Recording of geolocation data through the FollowMee app is accelerometer gated, meaning that participants' geolocation co-ordinates are updated whenever they start to move. When participants are moving, the FollowMee app updates their location at a specified sampling rate.

Therefore, the post-processing pipeline rests on the assumption that when participants' location is not being updated they remain in the same location.

Geolocation data has an inherent level of noise, so I postprocessed the data by adapting a previously implemented algorithm to account for the accelerometer gating in the current data. The algorithm removed a location coordinate if it created an angle between its immediately previous and subsequent data point that was less than .4 radians (22.92 degrees) and the time interval between the immediately previous and subsequent data point was less than five minutes (this processing step captures instances when the recorded location jumps rapidly due to the triangulation process). I also removed consecutive geolocation coordinates that were either duplicate coordinates or duplicate timestamps (in hours and minutes, points only seconds apart).

I used interpolation to up-sample participants' locations to one-minute intervals. I had two interpolation methods based on the conditions under which location was being interpolated.

1. When participants were moving (and location was updated at the sampling frequency), I interpolated locations by calculating the velocity required to travel between location updates in the recorded time interval and filling in location coordinates at one-minute intervals from the previous location to the current location according to this calculated velocity. This type of interpolation has been implemented in previous work (Heller et al., 2020; Saragosa-Harris et al., 2022).

2. I additionally implemented a custom-built algorithm to interpolate locations under the following set of conditions, most likely resulting from loss of signal when participants' phones were turned off: when the gap between location updates was greater than 10

minutes, the distance between location updates was greater than .05 miles (about the size of a New York City block) but less than one mile (this upper limit excludes periods of travel when signal was lost owing to travel by subway or airplane). Under such conditions, calculating the velocity between pre- and post-gap locations using the first interpolation method (described above) can produce an unrealistically slow velocity and therefore inflates the roaming entropy calculation by adding many locations between updates over an extended period of time. Instead, under these conditions, I calculated velocity between the post-gap location and two subsequent locations and used this velocity to interpolate across the time interval gap from the post-gap location backwards to the pre-gap location. Using this method, the participant appears to remain in the pre-gap location and then travel at a constant speed through the following three location updates.

Daily roaming entropy was calculated on interpolated data using the following equation:

$$\boldsymbol{RE = -\sum_{j=1}^{n}(p_{ij} \times \log p_{ij}))/\log(n)}$$

Where p_{ij} is the within-day historical probability that location j was visited by participant i, quantified as the proportion of the day spent in each unique location (number of minutes in that location divided by the 1440 minutes in a day) and n is the total number of unique locations on Earth at four decimal degrees of GPS resolution.

Roaming entropy is highest when participants spend the day moving between many locations and lowest when participants spend all their time in the same location. Roaming entropy is higher when participants evenly divide their time between multiple locations than when the same locations are each visited but only for a short amount of time. For example, roaming entropy would be higher on a day when a participant spent equal proportions of their day at home, at a café, at a shop, at work, and at a friend's house than another day where they visited all of the same locations but spent the majority of their day at home and quickly visited the café, work, shop and friend's house.

Novelty was calculated by computing the number of novel locations visited by each participant for each day of the study period. I coded a location as novel if it had not yet been visited during the study period. To avoid inflating the novelty measure early in the study period, I removed the first 10 days of data collection from this analysis. I used this measure to verify the relationship between days of higher roaming entropy and location novelty, which has been shown previously (Heller et al., 2020; Saragosa-Harris et al., 2022).

Social learning and task pre-processing and metrics

A technical problem during task recording meant that players' locations were occasionally not updated on some trials. These trials were removed from analysis. This affected 3–31 trials (M ± SD = 15.27 ± 5.28) of 210 trials.

The analysis only included trials on which participants had the opportunity to zap (positioned in the same column or row as another player): 31.5% of trials on average (SD = 7.5%, range 17.6–57.6%). Therefore, the analysis included 11–38 trials (M ± SD = 19.67 ± 4.83) per block per participant.

For generalised mixed-effects models I used trial-level data, with zapping (1 or 0) as a binary outcome variable. I conducted two separate mixed-effects models: 1) to investigate task-related factors associated with zapping, with block number, participants' distance to a star on each trial, participants' current score (number of stars collected) and participants' distance from their target player as predictors; 2) to investigate zap adaptation, with block number, block half (first or second half of block) and age group and all lower-level interactions and main effects as predictors.

I also calculated aggregate measures of zap behaviour to investigate the associations between task behaviour and real-world exploration, social contact gain, affect and mental health measures. I calculated the proportion of trials where participants zapped another player by summing the number of zaps over the number of zap opportunities per norm condition, to create two measures: zap probability during the competitive norm (block two) and during the polite norm (blocks one and three).

Results

Roaming entropy and location novelty

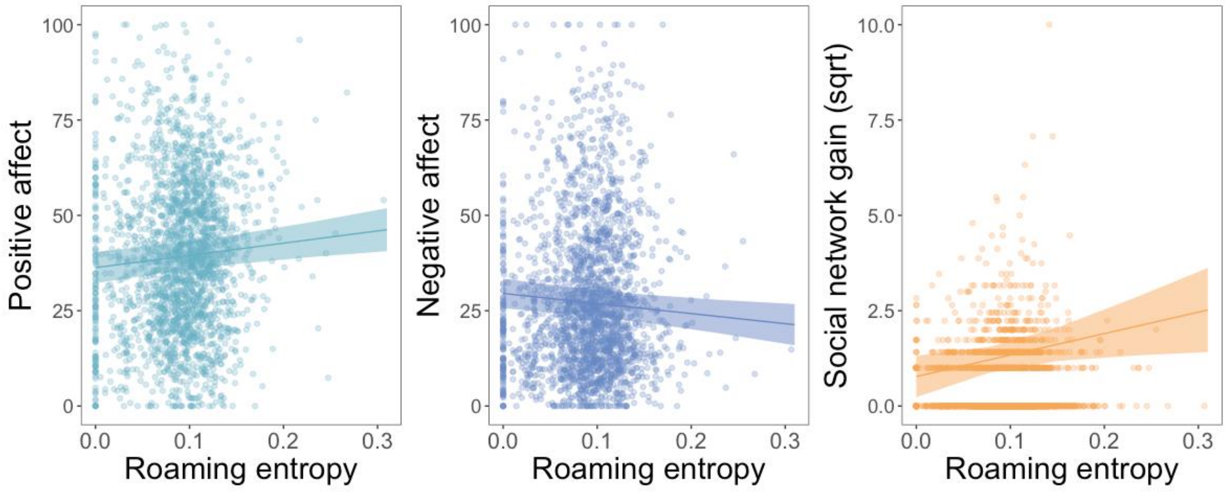
I used a multilevel regression with a zero-inflated negative binomial distribution, with roaming entropy (z-scored within participants) and novelty (daily count of novel locations) as the outcome. I replicated previous findings (Heller et al., 2020; Saragosa-Harris et al., 2022), demonstrating a positive association between roaming entropy and novelty (β = .80, *SE* = .01, z = 56.13, p < .001), which was robust to controlling for daily distance travelled (roaming entropy: β = .73, *SE* = .01, *z* = 49.12, *p* < .001; distance: β = .003, *SE* < .001, *z* = 10.79, *p* < .001).

Roaming entropy, affect and social contact gain

I confirmed my pre-registered hypothesis, that roaming entropy would be associated with greater positive affect (positive affect: $\chi2$ = 14.84, p < .001; Fig. 6.2, left panel), and also showed that roaming entropy was associated with lower negative affect (negative affect: $\chi2$ = 9.85, p = .002; Fig. 6.2, middle panel). As expected, roaming entropy was also significantly associated with gain in social contacts, in that participants added more new contacts to their phone on days when they roamed more ($\chi2$ = 11.02, p < .001; Fig. 6.2, right panel). However, on average roaming entropy was not significantly associated with greater feelings of autonomy ($\chi2$ = .24, p = .621).

Feelings of autonomy were associated with greater positive affect ($\chi2$ = 207.24, p < .001) and lower negative affect ($\chi2$ = 48.05, p < .001). Roaming entropy remained a significant predictor of positive and negative affect when also including autonomy in the model, but there was no evidence to support my hypothesis that autonomy would moderate the association between roaming entropy and positive affect (positive affect: $\chi2$ = 1.01, p = .314; negative affect: $\chi2$ = 2.58, p = .108).

Figure 6.2 **Associations between roaming entropy and affect and social network gain**

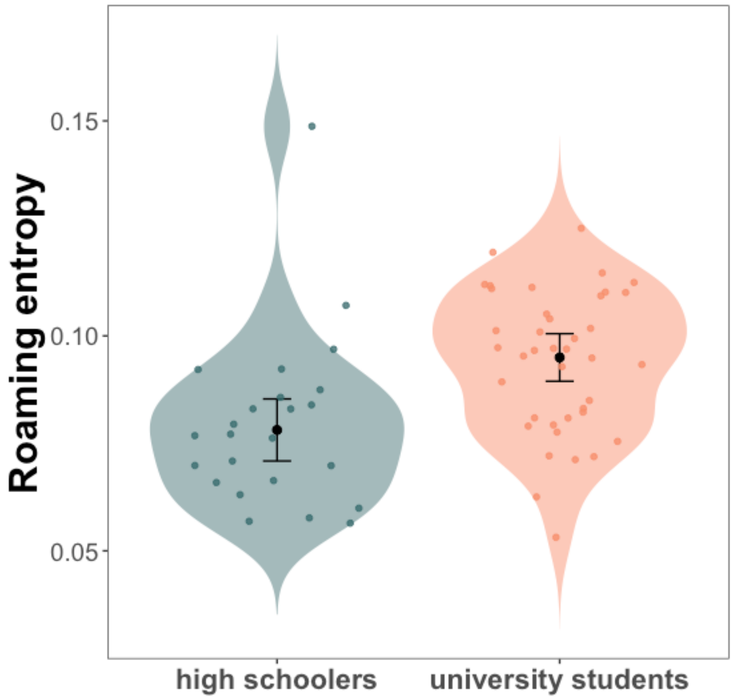


Note. Dots represent values for all participants across each day of the study period. Lines represent fixed-effects model estimate and ribbons represent 95% confidence intervals.

Associations with age group

As expected, roaming entropy was significantly higher in university students compared with high schoolers (β = .81, *SE* = 22, *t* = 3.64, *p* < .001; Fig. 6.3). There was no significant difference between age groups in overall social contact gain or reported feelings of autonomy (social contacts: β = .27, p = .329; autonomy: β = .27, p = .331).

Figure 6.3 **Average roaming entropy across age groups**



Note. Dots represent each participants' average roaming entropy over the study period. Violins plots show the distribution of average roaming entropy between age groups. Black dots and error bars represent model estimates.

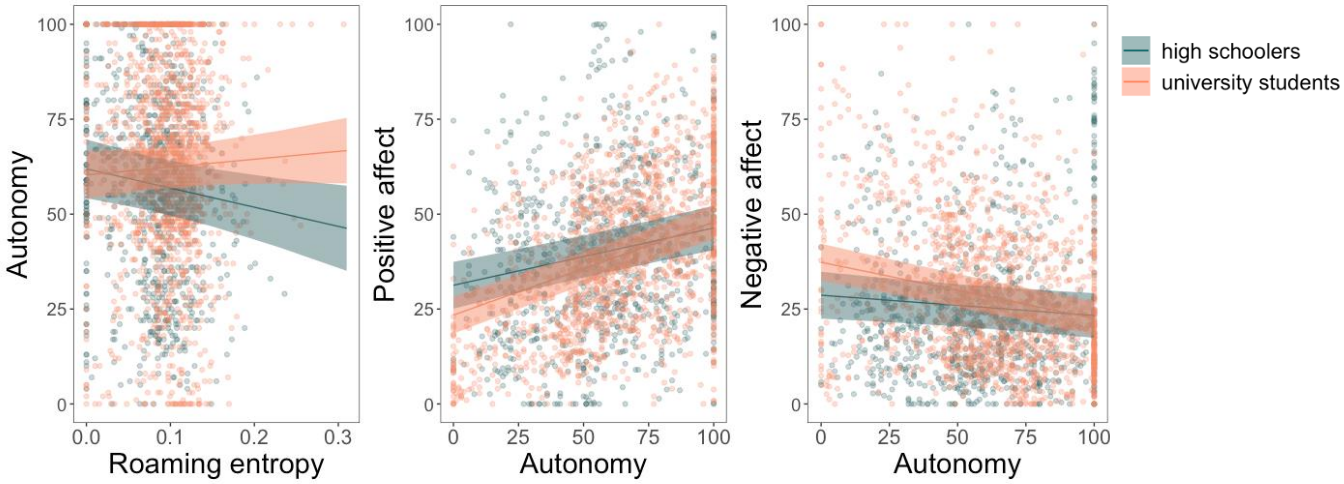
The associations between roaming entropy and positive affect, negative affect and social contact gain were not significantly moderated by age group (group-by-roaming entropy interaction, positive affect: $\chi 2$ = 3.31, p = .069; negative affect: $\chi 2$ = 1.01, p = .314; social contact gain: $\chi 2$ = .84, p = .360).

I conducted exploratory analyses to investigate age group differences in the association between roaming entropy, feelings of autonomy and affect. The association between roaming entropy and feelings of autonomy was significantly moderated by age group ($\chi 2$ = 5.29, p =

.021; Fig. 6.4, left panel). High schoolers felt lower autonomy on days that they roamed more ($slope_{HS}$ = -.08, SE = .04, p = .021) whereas the relationship between roaming and autonomy in university students was positive but non-significant ($slope_{CS}$ = .01, SE = .03, p = .639; $contrast_{HS-CS}$ = -.10, SE = .04, p = .024).

The relationship between autonomy and positive and negative affect was also significantly moderated by age group (positive affect interaction: $\chi2$ = 9.40, p = .002; negative affect interaction: $\chi2$ = 9.73, p = .002; Fig. 6.4, middle and right panel). Both high schoolers and university students reported less positive affect on days on which when they felt they had less autonomy ($slope_{HS}$ = .20, SE = .03, p < .001; $slope_{CS}$ = .32, SE = .03, p < .001) but this association was stronger in university students ($contrast_{HS-CS}$ = -.12, SE = .04, p = .002). Similarly, both groups reported greater negative affect on days when they felt they had less autonomy ($slope_{HS}$ = -.07, SE = .03, p = .024; $slope_{CS}$ = -.20, SE = .03, p < .001) but, again, this association was stronger in university students ($contrast_{HS-CS}$ = .13, SE = .04, p = .002). For both interactions, the clearest group differences were evident on low-autonomy days (Fig. 6.4).

Figure 6.4 **Difference across age groups in associations between roaming entropy, autonomy and affect**



Note. Dots represent data for each day of the study period for all participants. Lines represent fixed-effect model estimates and ribbons represent 95% confidence intervals.

Mental health

Participants' scores on the Mood and Feelings Questionnaire – Short form (MFQ-SF) and the Generalised Anxiety Disorder assessment (GAD-7) covered the entire range (0–26 and 0–21 respectively). Using the guideline cut-off of 12 on the MFQ-SF, there were 25 participants who scored above the cut-off on at least one entry (proportion of responses above clinical cut off ranged from 0–100%, mean = 17.58%, SD = 27.82%). Using the guideline cut-off of 10 on the GAD-7, there were 34 participants who scored above the cut-off on at least one entry (proportion of responses above the clinical cut-off ranged from 0–100%, mean = 26.95%, SD = 34.22%).

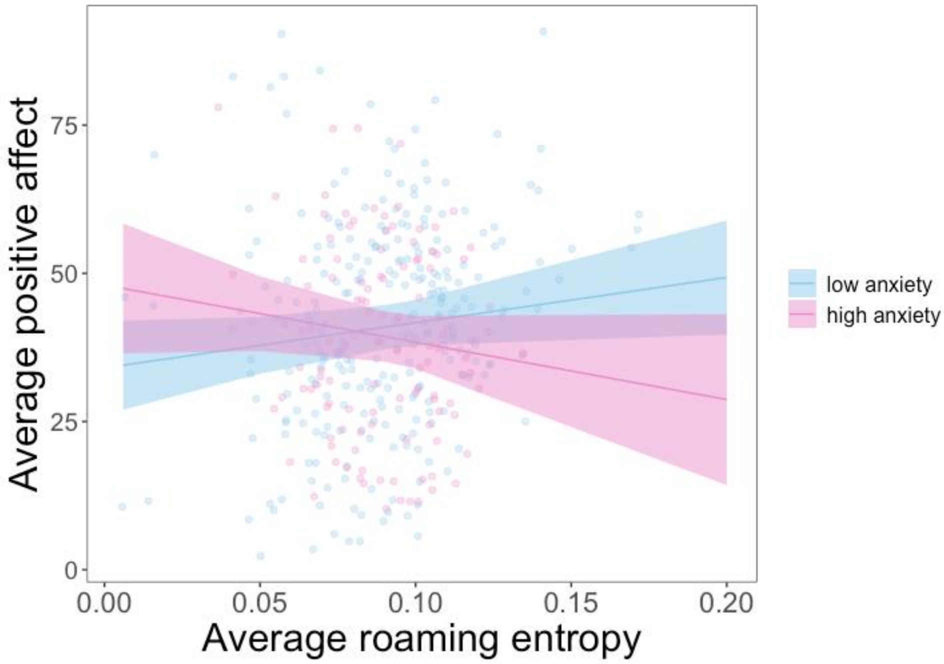
To test my preregistered hypotheses that poor mental health (measured using the Affect and Feelings Questionnaire – Short Form and Generalised Anxiety Disorder assessment every 2 weeks) would be associated with lower roaming entropy and social network gain, I averaged all measures over the subsequent two weeks following a mental health measure.

I did not find a significant association between mental health symptoms and average roaming entropy in the subsequent two weeks (depressive symptoms: $\chi 2 = .40$, $p = .527$; anxiety symptoms: $\chi 2 = .08$, $p = .782$).

As expected, participants with greater depressive symptoms reported lower average positive affect and greater average negative affect in the subsequent two weeks (positive affect model: $\chi 2 = 4.52$, $p = .033$; negative affect model: $\chi 2 = 32.82$, $p < .001$) but depressive symptoms did not moderate the association between roaming entropy and positive or negative affect in the subsequent two weeks (positive affect model: $\chi 2 = 1.29$, $p = .257$; negative affect model: $\chi 2 = 1.44$, $p = .229$).

Participants with greater anxiety symptoms did not report lower average positive affect in the subsequent two weeks ($\chi 2 = .19$, $p = .646$) but anxiety symptoms moderated the association between roaming entropy and positive affect in the subsequent two weeks ($\chi 2 = 5.93$, $p = .015$). I used the recommended cut-off of 10 or above on the Generalised Anxiety Disorder assessment to construct post-hoc contrasts, finding that those below the cut-off had a positive association between roaming entropy and positive affect, while those above the cut-off had a negative association. Although neither of these slopes on their own reached statistical significance in isolation, the contrast between slopes was significant ($\text{slope}_{\text{lowanxiety}} = .11$, SE = .06, p = .061; $\text{slope}_{\text{highanxiety}} = -.14$, SE = .09, p = .125; $\text{contrast}_{\text{high-low}} = .25$, SE = .09, p = .009).

Figure 6.5 **Difference between participants reporting high or low anxiety symptoms in association between roaming entropy and positive affect**



Note. Y-axis is average positive affect in the two weeks following a mental health assessment, x-axis is the average roaming entropy for the same period. Dots represent average data in the two weeks following a mental health assessment, for all participants. Lines represent fixed-effects model estimates and ribbons represent 95% confidence intervals. Data is categorised as low anxiety when participants score below the clinical cut-off on the Generalised Anxiety Disorder 7-item assessment (GAD-7) and high anxiety when participants score above the clinical cut-off on the GAD-7.

Participants with greater anxiety symptoms reported greater negative affect ($\chi2 = 57.70$, $p < .001$), but anxiety symptoms did not moderate the effect of roaming entropy on negative affect ($\chi2 = .02$, $p = .877$).

Depression and anxiety symptoms were also not significantly associated with social contact gain (depressive symptoms: $\chi 2$ = .04, p = .496; anxiety symptoms: $\chi 2$ = .02, p = .888) and the relationship between roaming entropy and social contact gain was not significantly moderated by depression or anxiety symptoms (depressive symptoms: $\chi 2$ = .84, p = .358; anxiety symptoms: $\chi 2$ = .09, p = .120).

Social anxiety symptoms (measured only on day one of the study) were not significantly related to average roaming entropy or total number of new social contacts made during the measurement period (roaming entropy: β = .10, SE = .33, *p* = .754; social contact gain: β = .10, SE = .14, *p* = .504).

Social learning task performance

Overall, as expected, participants increased their zapping from block one to block two (polite to competitive: *t*(128) = -2.09, *p* = .038; Table 6.1) and decreased their zapping again from block two to block three (competitive to polite: *t*(128) = 2.71, *p* = .008, Table 6.1). There was no significant difference in zapping behaviour between block one and block three (polite blocks: *t*(128) = .72, *p* = .475, Table 6.1).

Table 6.1 **Social learning task behaviour.**

Block	Mean (SD)	95% CI
1 Polite	0.266 (0.174)	[0.224, 0.307]
2 Competitive	0.336 (0.216)	[0.285, 0.387]
3 Polite	0.244 (0.177)	[0.202, 0.287]

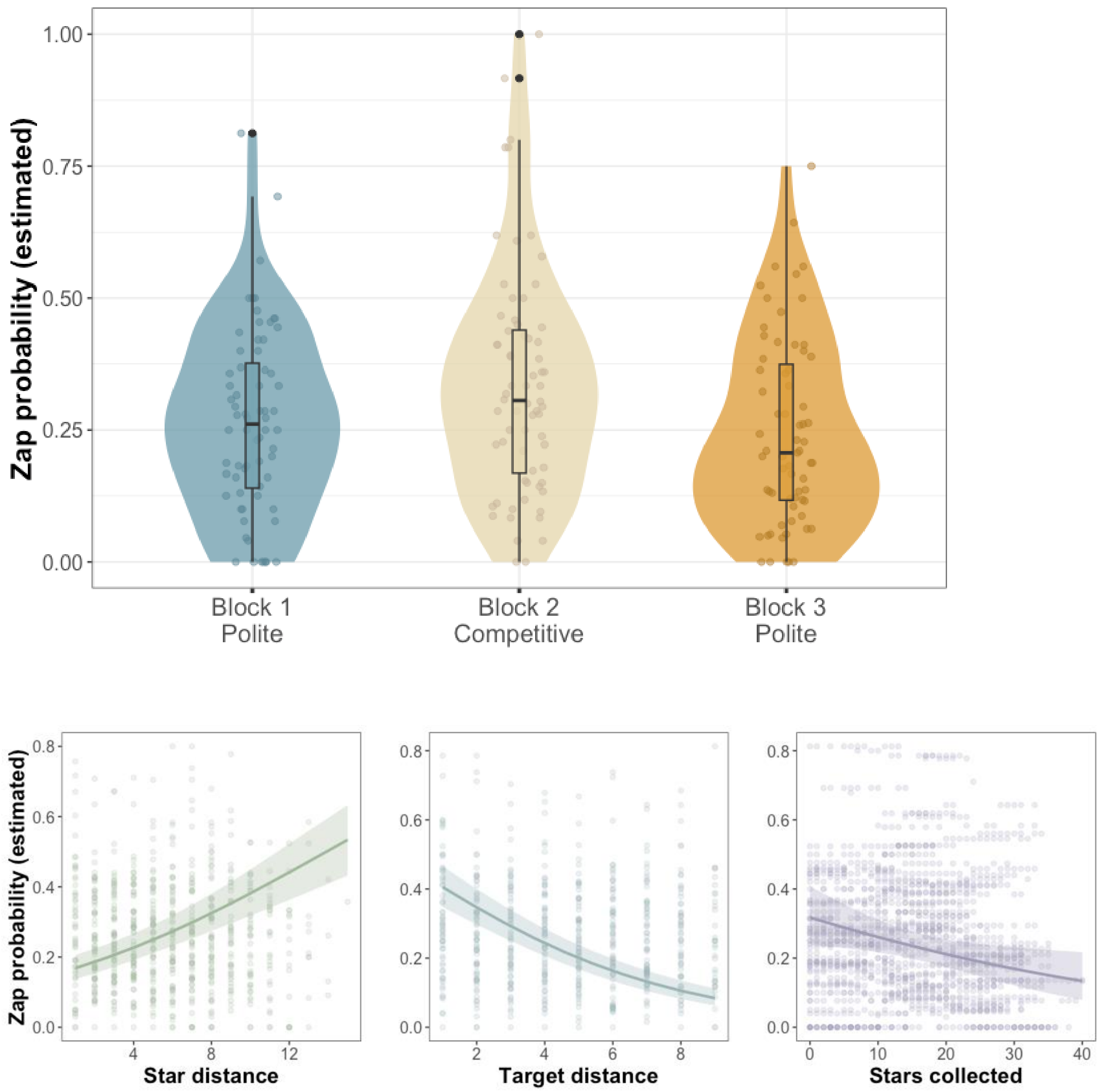
Note. Mean zapping behaviour per block, with standard deviation and 95% confidence intervals.

To investigate the factors that influenced participants' zapping behaviour, I conducted a mixed-effects model on trial-level behaviour with zap (1 or 0) as the outcome and the following task factors: block number (1-polite, 2-competitive, 3-polite), block half (first or second), participants' distance from the nearest star, participants' score (number of stars collected) and participants' distance from their target. Participant ID was included as a random intercept.

This mixed-effects model confirmed that zapping behaviour was significantly influenced by block ($\chi 2$ = 12.76, p = .002; Fig. 6.6, upper panel). Participants were more likely to zap other players during the competitive block than during both of the polite blocks and there was no significant difference in zapping between the two polite blocks ($\text{contrast}_{\text{Block1-Block2}}$ = -.43, SE = .14, p = .004; $\text{contrast}_{\text{Block2-Block3}}$ = .46, SE = .12, p < .001; $\text{contrast}_{\text{Block1-Block3}}$ = -.03, SE = .14, p = .975). Confirming results previously reported in an adult sample (U. Hertz, 2021), participants were also more likely to zap when they were further from their nearest star ($\chi 2$ =

52.48, $p < .001$), when they had collected fewer stars already ($\chi2 = 6.05$, $p = .014$), and when they were closer to their zap target player ($\chi2 = 123.02$, $p < .001$; Fig. 6.6, lower panel).

Figure 6.6 **Social Learning task performance**



Note. Zap probability is estimated as the number of trials on which participants zapped over the number of trials on which they had the opportunity to zap another player. Upper panel shows zap probability across the three blocks. Violins show the distribution of zap probability and box plots show the median and interquartile range. Dots show the individual participant estimates. Lower panel shows associations between star distance, target (another player's) distance, and number of stars collected and zap probability. Dots represent all trials for all participants. Lines represent fixed-effects model estimates and ribbons represent 95% confidence intervals.

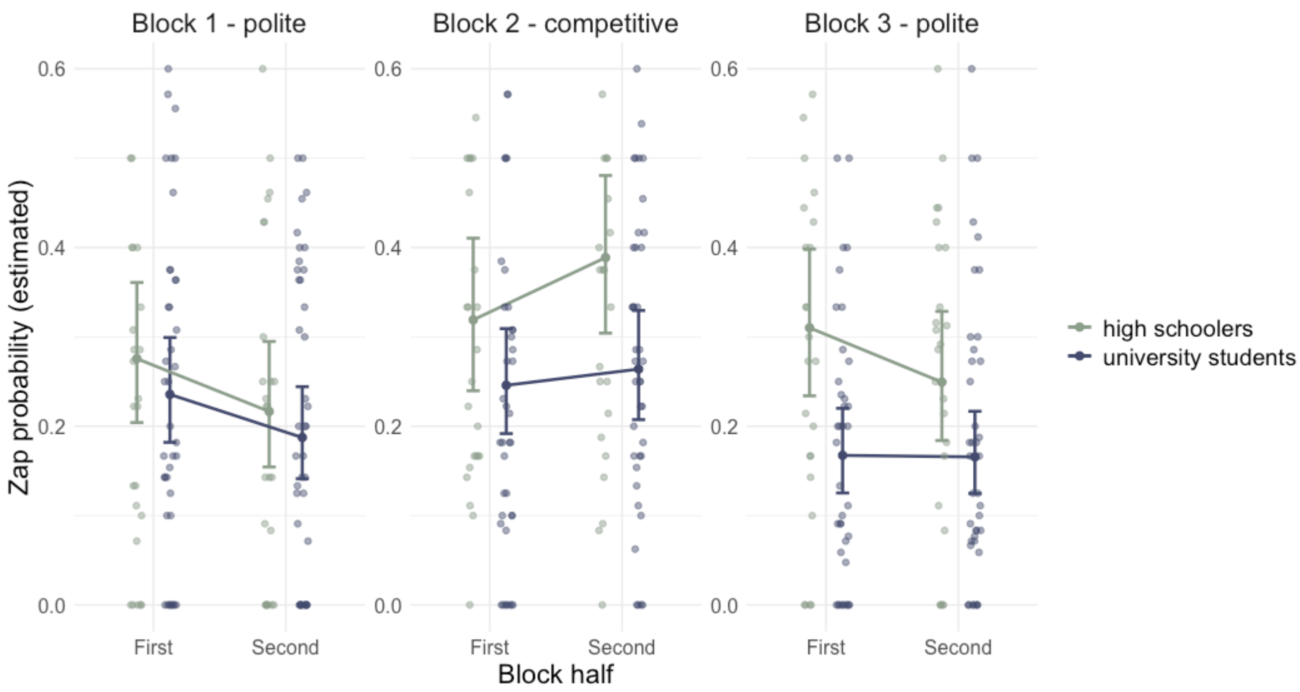
Age-related change in social norm learning

To analyse age-related changes in norm learning, I conducted a mixed-effects model with age group (high schoolers (13–15-year-olds) versus university students (17–19-year-olds)), block half (first or second) and block number (1, 2 or 3), and their interactions, as predictor variables predicting trial-level zaps (1 or 0).

There was a significant interaction between block half and block number ($\chi2$ = 6.20, p = .045). Post-hoc contrasts revealed that there was a significant difference in zapping between the first and second halves of block one ($\text{contrast}_{\text{Second-First(Block1)}}$ = -.31, SE = .14, p = .030) but that there was no significant difference between halves in the second or third blocks ($\text{contrast}_{\text{Second-First(Block2)}}$ = .20, SE = .13, p = .119; $\text{contrast}_{\text{Second-First(Block3)}}$ = .16, SE = .14, p = .243).

The main effect of age group was non-significant ($\chi2$ = .66, p = .418), showing that the age groups did not differ in their overall probability of zapping other players. The interaction between group and block number was non-significant ($\chi2$ = 5.15, p = .076) and the interaction between block number, block half and age group was non-significant ($\chi2$ = 1.79, p = .409).

Figure 6.7 **Age-group differences in zap probability across block halves**



Note. Dots represent each participants' zap probability, estimated as the number of zaps over the number of zap opportunities. Solid dots represent fixed-effects model estimates and error bars represent 95% confidence intervals, estimates are joined by solid lines to show differences between block halves.

Associations between task measures and real-world measures

I next tested my pre-registered hypotheses that adolescents who were better at adjusting to new social norms would gain more (in terms of affect and social contacts) than adolescents who adjusted their behaviour less to new norms.

To test this hypothesis, I inspected the interaction between roaming entropy and probability of zapping in the competitive block, while controlling for mean probability of zapping in the polite blocks. The relationship between roaming entropy and affect was not significantly modulated by zapping behaviour ($\chi2$ = .14, p = .710), and neither was the relationship between roaming entropy and new social contacts ($\chi2$ = .32, p = .573).

Discussion

I investigated the relationship between adolescent behaviour, roaming entropy, social contacts, affect, and mental health symptoms during a formative transitional experience: the start of a new school or university. Young people in the first three months of either high school (13–15-year-olds) or university (17–19-year-olds) took part in the study. I investigated behaviour on an experimental task as well as real-world behaviour via geolocation and ecological momentary assessment. I measured roaming entropy, a measure of exploration, and replicated previous findings showing this was significantly associated with experiential novelty. I also found that roaming entropy was significantly associated with benefits for young people, including increased positive affect, decreased negative affect and gaining more new social contacts. Interestingly, the different age groups had different experiences of roaming. High school students reported feeling lower autonomy over their activities on days where they roamed more, whereas university students reported the opposite. When participants felt less autonomy over their activities, they reported lower positive affect and greater negative affect. This association was stronger for university students, who were particularly negatively affected when they felt they had little autonomy. Behaviour on a social norm learning task did not appear to be associated with the benefits of roaming. Although mental health symptoms were not related to lower roaming entropy overall, anxiety symptoms appeared to disrupt the association between roaming entropy and positive affect, with young people scoring above the clinical anxiety cut-off reporting lower positive affect on days when they roamed more.

Students who were in their first three months at university explored more than high schoolers in their first three months at a new school. This replicates previous research, suggesting that exploration increases as individuals acquire autonomy (Saragosa-Harris et al., 2022; Spear, 2000a). At the transition to university, many geographical and social constraints on young people are relaxed. Whereas in high school, adolescents tend to be constrained to a strict schedule of classes in a single geographical location, university classes tend to be taken in various locations with schedules differing daily. Adolescents are also afforded more freedoms as they enter legal adulthood and financial independence. Therefore, greater exploration may be partly due to greater opportunity to express a heightened propensity for novelty. During the transition to university, adolescents typically move away from home and live independently, often in shared accommodation with same-aged peers, in a new city, state or even a new country. Therefore, adolescents may explore as an adaptive response to this hyper-novel scenario, as a way of gathering information about their physical and social environment. As such, exploration may be a response to the novelty itself rather than a novelty-seeking activity. In future research it would be important to measure adolescent behaviour before, as well as during, the transition to a new school in order to investigate whether individuals increase their exploratory behaviour during the school transition. It is also important to note that the students selected in this sample may be particularly exploratory or novelty seeking, having chosen to attend university in a large, highly culturally diverse city. Similarly, the high schoolers in this sample may be afforded different freedoms to high schoolers in other cities or more rural parts of the United States. Future comparisons of adolescents in different roles (e.g. university students versus full-time workers) and in different geographical locations (e.g. urban versus rural settings) could help to disentangle these influences on exploratory behaviour.

Increased exploration has been proposed to facilitate adolescents' transition towards independence (Spear, 2000a). I found that exploration (indexed by roaming entropy) and autonomy showed different relationships between the different age groups. University students showed a (non-significant) positive relationship between autonomy and exploration whereas high schoolers reported feeling less autonomy on days where they explored more. This may reflect that, exploration in high schoolers is mostly driven by obligations – travelling to school or being taken to activities with caregivers – whereas for university students exploration includes more varied activities that are likely both self-directed and driven by obligations (e.g. attending classes).

I also showed that university students had a stronger relationship between autonomy and affect than high schoolers. Experiences of autonomy were more strongly associated with increases in positive affect and decreases in negative affect for university students compared to high schoolers, which seemed to be driven primarily by situations in which perceived autonomy was low. In Chapter 5, I showed that as adolescents develop they are better able to learn about themselves through independent choice, and suggested that learning through choice is rewarding. Here, I showed that making choices in real-world settings was more rewarding for university students than high school students. Perhaps this is reflective of a similar process: when making decisions for themselves, university students were able to learn more about themselves (and their environment) and reduce their uncertainty in their own preferences. Further, if the university-aged adolescents had more certainty in their own preferences then making choices may have led to more rewarding activities than for high schoolers. For high schoolers, novel experiences may be tempered by loss of autonomy.

Both groups showed significant coupling between roaming entropy and affect, in that day-to-day affect varied with daily real-world exploration. This replicates previous cross-species research in adolescents and adults. This drive to explore may be due to intrinsically rewarding properties of novelty (Kakade & Dayan, 2022; Krebs et al., 2009; Wittmann et al., 2007). I did not find a significant age-related difference in the association between roaming entropy and affect. This appears to stand in contrast to research proposing that adolescence is associated with heightened sensitivity to rewards and heightened sensation-seeking (Chein et al., 2011; Steinberg et al., 2018). However, according to most definitions, all participants in the sample were adolescents and previous studies have suggested peaks in reward sensitivity across the age range recruited here (e.g. quadratic association across ages 8–25: Braams et al., 2015). Thus, I may not have recruited a sufficiently wide enough age range to detect developmental differences in reward-related affect. The affect surveys were also distributed at random intervals during the day, so may not have been temporally precise enough to capture adolescents during experiences of novelty. Future studies could consider triggering affect surveys when participants enter a novel location, to better detect the potentially transient rewarding nature of novel experiences.

The motivation to explore new environments may be accompanied by a similar desire to engage in new social experiences. This study demonstrated that on days that participants roamed more, they also gained more new social contacts. Previous research has indicated that average roaming is associated with larger social networks, as measured at a single time point midway through the study. To explore this finding further, I instructed participants to consider new contacts as individuals they had met face-to-face and added to their phone for ongoing communication, via any app. This approach allowed me to expand upon previous findings in important ways. Firstly, the current investigation focussed on within-person analysis, therefore accounting for between-subjects variation in roaming and individual differences in traits (e.g. extraversion) that may influence both roaming and social networking. Second, by investigating the association between daily roaming and daily increase in social contacts, I can infer more confidently that roaming plays role in building one's network, rather than it being a consequence of already having a large network. The results highlight the potential social significance of exploring new environments, particularly during transitional periods in adolescence such as starting a new school, when individuals are gaining independence and forming their own social networks.

Through the social norm learning task, I investigated whether the ability to adjust to new social norms would facilitate young people in gaining social contacts through roaming. As previously demonstrated in older samples, participants adjusted their behaviour to the different norms in the task, zapping other players more when the group norm was to play competitively and zapping other players less when the group norm was to play politely. I also found signs of learning across the block; with increased observations of other players, participants adapted their behaviour to fit with the norm of the group.

I also predicted that university students would be better at learning new social norms and would adapt their behaviour more readily. However, I did not find any evidence of age-related differences in behaviour on the task. On average, participants at all ages adapted their behaviour on the task to fit with new social norms, increasing their zapping when the norm was competitive and decreasing it when the norm was polite. In contrast to previous work (U. Hertz, 2021), I also showed that participants adapted their behaviour to a similar extent when transitioning from a polite to a competitive social norm and when transition from a competitive to a polite social norm. In earlier studies, this adaptation was stronger when transitioning from polite to competitive than from competitive to polite, where participants continued to show a high level of zapping once transitioning to a polite environment. This difference between the current study and previous work could be driven by adolescents being more sensitive and responsive to changes in social norms. Previous work showing that conformity to social norms decreases across adolescence and into adulthood has often included a wider age range than tested here (Ahmed et al., 2020; Chierchia et al., 2020b; Foulkes et al., 2018). Furthermore, it is important to note that due to difficulty in recruiting a large sample during such a specific time frame, I may be underpowered to detect age-related changes on task performance. There are also methodological differences between the current task design and that used previously. For example, I added an interactive practice session and instruction comprehension tests to ensure participants understood how to zap other players. Without this, if participants in the previous study did not attend closely to the instructions, they may not have realised they could zap other players until transitioning to a competitive social norm. I also tested transitions in both directions within-subject by asking participants to complete three blocks instead of counterbalancing the order between two blocks between-subjects, as in Hertz (2021), which may have affected how participants responded to transitions between norms.

A limitation of the social norm learning task design is that it does not allow me to dissect the influences of different cognitive processes on behaviour; for example, how well participants learned the norm through observation versus how much they adapted their behaviour to fit with the norm. Future work should aim to differentiate these influences on behaviour, which could be achieved by surveying participants' awareness of the norms as well as observing changes in behaviour. The behavioural prescriptions created by the norms in the task may also be relevant for understanding why I did not observe the hypothesised associations between social norm learning, exploration and social network gain. In the social learning task, the change in social norms involved increasing or decreasing harmful behaviours to others, but it would be interesting to explore adaptation to norms that require participants to increase or decrease positive behaviours, which may be more relevant for explaining variation in social network gain through exploration. Furthermore, it would be worthwhile comparing performance on the social learning task to a non-social task measuring general cognitive flexibility (e.g. Wisconsin Card Sorting Task; Heaton, 1981) to investigate whether behaviour on this task is specific to social behaviours or reflects behavioural flexibility more generally.

Moreover, the use of 'roaming entropy' as a measure of exploration has certain constraints. Primarily, roaming entropy does not account for the novelty of locations day-to-day. For example, participants could garner a high daily roaming entropy score if spent time in many unique locations during the day, but this would remain a high score, even if they were visiting the same locations in the same sequence every day. I showed that roaming entropy was associated with a measure of 'novelty', a metric that does account for repeated visits to locations across days, but perhaps a new measure is needed that amalgamates the advantages of both measures. One such way to capture this could be to measure habit formation using the geolocation data. To do this, one could map the Euclidian distance between the paths taken on each day, to look at deviation from the routine of the previous day. This measurement may better capture true experiences of novelty.

I found that greater roaming entropy was related to lower feelings of autonomy in high school students, which was not the case for college students. This discrepancy suggests that the nature of the activities being undertaken during roaming are dissimilar across the age groups. Therefore, the experiences of these groups during exploration are not equated and are not easily comparable. For instance, it is conceivable that the association between self-directed, novelty-seeking exploratory behaviours and affect is stronger in high schoolers than college students. However, discerning such differences is impeded by the comparison of predominantly non-autonomous exploration in the high schoolers with self-directed exploration in the college students. Lastly, the acquisition of baseline measures of roaming entropy prior to joining a new school would enable more robust inferences regarding whether exploratory behaviour changes in response to environmental novelty.

The power analysis indicated that I was only able to detect medium effect sizes in the study, given the sample size collected (which was constrained by the short recruitment window for participants to enrol). Therefore, I may have been underpowered to detect between-subjects differences, including any age group differences or mental health differences. Therefore, the results presented in this chapter should be interpreted with caution and replication is necessary in an independent sample to have confidence in the novel findings.

Finally, I measured symptoms of depression and anxiety every two weeks. Adolescents in the current sample showed a range of symptoms throughout the 3-month period but few participants reached a clinical level. In contrast to previous research showing decreased exploration in anxiety (Biedermann et al., 2017; Walz et al., 2016) and depression (Saeb et al., 2015, 2016), I did not find that symptoms impacted the amount that adolescents explored or the number of new social contacts they made during their first three months at their new school or university. This was potentially affected by the levels of depression and anxiety, which may not have been high enough to impact on every day functioning. However, I did find that when participants reported clinical levels of anxiety, this disrupted the relationship between roaming and positive affect for the subsequent two weeks. In fact, when adolescents reported clinical levels of anxiety, the usual association between roaming and positive affect was reversed, albeit this association was non-significant in isolation. Anxiety symptoms are consistently associated with intolerance of uncertainty in adults and adolescents and lower need for risk taking (Dekkers et al., 2017; Wright et al., 2016). Therefore, when anxiety symptoms peak they may reduce adolescents' ability to take enjoyment from novelty because the uncertainty associated with novel environments becomes less tolerable, and acting in this uncertainty becomes more difficult.

In summary, this study provides evidence for the importance of exploration in promoting the wellbeing of adolescents and facilitating the establishment of social connections. However high schoolers and university students experienced exploration differently; with high schoolers reporting less autonomy over their actions on days when they explored more, whereas university students reported a similar amount of autonomy across different levels of roaming entropy. High schoolers also reported less of an impact of feelings of autonomy on their affect than university students. These results raise the possibility that promoting young people's feelings of autonomy may better allow them to experience the benefits of exploration.

Chapter 7

General Discussion

The studies presented in this thesis contribute to a larger literature suggesting that adolescence is a formative period for self-concept construction and the development of independent decision-making capacities.

Summary of findings

In my first study (Chapter 3), I asked whether the ability to accurately reflect on our own decisions continues to develop through adolescence and whether this ability could drive independent decision making. I showed that metacognitive efficiency matures from childhood (8–9 years) to adolescence (12–13 years), meaning that 12–13-year-olds' confidence ratings better distinguished between correct and incorrect decisions. The oldest group (16–17-year-olds) did not show any difference from the younger adolescents. In parallel, I showed that adolescents' ability to incorporate advice into their decisions improved over the same age range. Twelve–13-year-olds were better able to successfully reject false advice but still take on helpful advice from others. I used mediation analysis to provide preliminary evidence that these processes were linked. I interpreted these results as indicating that adolescents, compared with children, followed conflicting advice less often when they were correct but took it when they were incorrect *because* they were better able to intuit whether they were correct or not. This provides an initial indication that developing self-reflection capacities may be an important part of the path to independence for adolescents. I also found that 12–13-year-olds were more confident overall in their decisions than the older adolescents (16–17-year-olds) and children (8–9-year-olds). However, in contrast to my predictions, I did not find any evidence for associations between mental health symptoms and metacognitive or advice-taking behaviour; albeit owing to the limited sample size these null results should be treated with caution. Further research is needed to investigate the interactions between metacognitive development and the emergence of mental health disorders, an inquiry that would benefit most from longitudinal studies in larger samples.

In my next study (Chapter 4), I was particularly interested in the reduction in confidence from early to late adolescence observed in Chapter 3 and tested whether this would be generalised to judgements of our own traits, creating more negative appraisals. As hypothesised, I found that willingness to endorse negative traits showed an age-related increase across adolescence, peaking around age 19 (which is the peak age for depression onset; Solmi, et al., 2019). I was also interested in what self-referential processing could reveal to us about how information is gathered to form a self-concept in adolescence. To this end, I used a self-referential memory task and a self-referential associative matching task. The self-referential memory task was evaluative, meaning that I could investigate age-related change in the effect of valence on memory biases for self-relevant information. On the other hand, stimuli in the associative matching task were neutral, allowing me to assess whether the basic prioritising of self-relevant information changed across adolescence.

I predicted that both tasks would show heightened self-referential processing in early adolescence, based on the hypothesis that early adolescents would be most motivated to gather self-relevant information whether it was evaluative or neutral. However, I only found an age-related association with behaviour on the evaluative memory task: younger adolescents showed the strongest self-reference effect, remembering more self-judged words than other-judged words, and the magnitude of this effect reduced with age. In the associative matching task, the self-reference effect (which here refers to faster and more accurate matching judgements for self-associated compared to other-associated stimuli), remained stable across the age range. Of course, the valence of the stimuli is not the only difference between these tasks; they measure very different mechanisms of self-referential processing. Consequently, the different patterns of association with age may be due to different trajectories of development in memory versus perceptual decision-making capacities. One takeaway from this study was the importance of evaluative information for younger adolescents in self-concept development. When assessing the valence of the stimuli, younger adolescents also showed a lower positive bias (the tendency to remember more positive than negative words) and the magnitude of this bias showed an age-related increase. I interpret this interesting developmental change in memory for self- vs other-judged valenced words as indicating that earlier in adolescence, when individuals are learning rapidly about themselves and others, it may be important to hold a balanced view of the self and others.

Next, I turned to investigating the development of preferences, another important aspect of the self-concept. I was motivated by considering the parallel processes during adolescence of constructing a self-concept and gaining autonomy in everyday life. Over the course of adolescence, young people are increasingly allowed to make decisions for themselves, for example, what clothes to wear, what music to listen to and where and with whom to socialise outside of school. I was interested in whether this increased autonomy over everyday decisions could itself help adolescents learn about their own preferences.

To investigate this, in Chapter 5, I drew on the literature on CIPC. This body of work revolves around a well-established phenomenon known as Spreading of Alternatives (SoA): the reliably observed tendency for individuals to increase their enjoyment ratings for items that they chose, while decreasing ratings for items they did not select. Previous work has suggested that the process of choosing itself allows participants to reassess and refine their preference estimates in order to reach a choice. However, there is an alternative explanation for this pattern based on the statistical artefact of regression to the mean (Chen & Risen, 2010). To take this potential confound into account, I designed a study that could measure value refinement while also accounting for the statistical artefact explanation by incorporating a control condition in which choices were made based on colour, not preference. Through this, I could assess age-related changes in the ability to update preference estimates through choice, while accounting for apparent changes that may be due to the statistical artefact.

In Chapter 4, I observed that younger adolescents found self-referential information more salient (showing a larger self-reference effect in memory). Therefore, in Chapter 5, I predicted that younger adolescents would show greater updating of their preferences through choice, and that this would reduce with age. However, instead I found that the ability to use choice to refine and reassess preferences increased across age. Potentially, this points to an interesting disparity between motivation and capacity., which is revealed by considering Chapter 4 and 5 together: perhaps *motivation* to gather information about the self is strongest in younger adolescents, but their *capacity* for self-concept formation through choice is still developing. In Chapter 5, I did also attempt to test whether the process of making self-related choice was intrinsically rewarding for young people, designing a new task in which participants could choose to forego monetary reward in a boring repetitive task to answer self-preference questions. However, owing to the shortcomings of the task design, unfortunately the results of this part of Chapter 5 were not illuminating.

In Chapter 5, I also measured depressive symptoms to assess how the presence of these symptoms affects the ability to update preferences through choice. In direct contrast to my predictions, depressive symptoms were associated with greater value refinement. However, depressed participants remained less certain about their values and less confident in their choices. Depression is often associated with difficulty in decision making (one of its core symptoms), so it is surprising that depressive symptoms were associated with greater "learning" about self-preference through choice. One possible explanation for this counter-intuitive pattern of results is that the difficulty reported by depressed people in making decisions arises from feelings of uncertainty about values and decisions, rather than difficulty in the decision process itself. However, this requires testing in future experiments specifically designed to test this hypothesis.

My attempt to measure the rewarding nature of value refinement through designing a novel task was unsuccessful for a number of reasons (see Chapter 5 Discussion). In my next study (Chapter 6), I took a different approach to studying the rewarding nature of making independent decisions in adolescents. I wanted to capture the increasing autonomy that adolescents experience as they mature: rather than being compelled to undertake activities by their parents or teachers, they instead start to have the opportunity to explore by themselves. This might start in smaller ways, for example, being able to stop off at a friend's house on the way home from school, growing into greater independence until adolescents finally move out of home and decide almost everything for themselves. In order to capture this, I measured two groups of adolescents at transitional phases of life: high schoolers (13–15-year-olds) in their first three months of a new New York City high school and university students (17–19-year-olds) in their first three months of NYU. I initially asked the students to take part in a social norm learning task, in which they interacted with other virtual players whose behaviour was determined by different norm algorithms in different blocks of the task. I then observed this group of students for three months, continuously recording their geolocation using a mobile app and asking them to respond to affect surveys and questions about their autonomy and new social contacts every other day. I also recorded their mental health every two weeks through two questionnaires measuring depression and anxiety symptoms.

In Chapter 6, I was motivated by previous work showing that roaming entropy, a measure of real-world exploration, was related to positive affect and larger social network sizes, and wanted to extend this work to explore the impact of autonomy. I found that, for high schoolers, roaming was associated with lower feelings of autonomy whereas for university students the relationship was positive (although this was not significant). Further, I found that lower feelings of autonomy were related to lower positive affect and greater negative affect, and not feeling autonomous had a greater impact on affect for the university students than for the high schoolers. Combined with the result in Chapter 5, showing that older adolescents are better able to learn about themselves when making their own choices, these results suggests a growing importance for autonomy across adolescence.

Through this study I was also able to assess another marker of independence: growing your own social network. I found that real-world exploration was associated with social network growth. This effect was not modulated by age group, suggesting that exploration is beneficial for social networking at all ages of adolescence. Contrary to my hypothesis, I did not find evidence that performance on the social learning task modulated this effect either. One possible explanation for this could be that the task measured antisocial behaviour adaptation (increasing or decreasing harmful zaps) rather than prosocial (where the behaviour would benefit others).

Interestingly, I did not observe any associations between roaming entropy and mental health symptoms. This contrasts with previous investigations illustrating a negative relationship between depression and levels of exploration utilizing analogous measures to those employed in the present study. There are several possible explanations that may account for this unexpected result. First, it is plausible that the range of depression and anxiety symptoms exhibited by the participants was not large enough to detect discernible relationships with behaviour. Second, it is worth considering that the study participants were adolescents only, a demographic known for their proclivity towards exploratory behaviours, which may render them less susceptible to the impact of mental health symptoms on their inclination to engage in exploration. Third, all participants were in the first three months of their new school or university. Consequently, it is conceivable that exploration held a particularly high value during this time frame, or alternatively, the sense of obligation towards attending classes and other scheduled activities could have been overwhelmingly dominant, thereby compelling individuals to persist in roaming despite heightened levels of mental health symptoms. I did find that when anxiety symptoms peaked for participants, this disrupted the association between roaming entropy and positive affect in the following two weeks. One possible interpretation of this result is that when participants were experiencing heightened anxiety symptoms, this did not affect their exploratory behaviour *per se* but instead reduced their enjoyment in exploration. Alternatively, it could be that the activities they were undertaking when exploring were less enjoyable. In future studies, obtaining more fine-grained details on the reasons for exploration could help to better explain these observed effects, for example, combining geolocation with detailed diary measures.

In summary, the findings of this thesis demonstrate that adolescence is a formative period of self-concept development and autonomy. Self-concept development is underlined by an increasing ability to reflect on our own decisions that appears to develop in early adolescence (Chapter 3). This heightened introspective capacity potentially facilitates a parallel process of introspection about our personal traits. Early adolescence also appears to be a unique period for self-concept development, demonstrating particularly strong prioritisation of self-referential trait adjectives in memory but also less of a positive bias in memory for all trait words (Chapter 4). As adolescents matured, they increased endorsements of negative traits about themselves, although on average participants at all ages endorsed more positive than negative traits. One possible explanation for this pattern of results is that the increasing ability to make more realistic judgements of their own performance, could feed into adolescents' judgements of their traits, creating on balance more negative endorsements (although, this hypothesis needs to be directly tested in future work).

Adolescents' capacity to reflect on their decisions appeared to allow them to make better independent decisions, enabling them to ignore misleading advice while still accepting helpful advice (Chapter 3). In turn, these independent decisions themselves may allow adolescents to refine their preferences, with the capacity for such value refinement likely expanding alongside the increasing autonomy experienced during the transition to legal adulthood (Chapter 5). Interestingly, adolescents just beyond the threshold of legal adulthood were especially negatively impacted by days characterized by limited autonomy, exhibiting heightened negative affect and reduced positive affect compared with younger adolescents when reporting low feelings of autonomy (Chapter 6).

Taken together, the findings of my four experiments suggest a number of strategies that adolescents may use to process, store and refine information related to their self-concept, ultimately facilitating their journey towards independent adulthood. I now turn to the methodological and theoretical limitations, followed by some of the potential implications of my work for developmental theory, mental health and social policy.

General methodological and theoretical limitations

In addition to the specific experimental constraints mentioned in Chapters 3–6, the work in this thesis should be interpreted within the context of a number of limiting factors. A first major limitation is that the various chapters assessed different age groups, making comparisons across chapters difficult. Chapter 3 was part of a wider project, meaning that I had less control over the selection of the age range. In Chapter 4, I selected the age range to cover the length of adolescence as defined by Sawyer et al. (2018) of 10–24 and into adulthood, but because in the UK children enter high school aged 11, I did not recruit any 10-year-olds. In Chapter 5, I used monetary bonus reward and I was only able to provide payment in vouchers due to the ethics protocol. Therefore, I only recruited school-age adolescents aged 11–18 because I was not able to replicate the same testing conditions and rewards in adults (I would have needed to test participants individually and pay by transferring money, given UCL Covid guidelines at the time) and I was concerned that this would confound the results. This also allowed me to match the testing conditions across age, which was a limitation of Chapter 4 as older participants were tested in smaller groups whereas adolescents were tested in classrooms. In Chapter 6, I selected the samples based on starting a new school and therefore I was limited to specific age groups.

A second limitation is that all of my developmental comparisons were cross-sectional and not longitudinal, rendering them vulnerable to cohort confounds. Chapter 3 was initially designed as a longitudinal study, but the follow up was scheduled for March 2020 when the first Covid-19 lockdown came into force. Importantly, the majority of my studies have been associative in nature and this limits my ability to draw causal conclusions when interpreting the results.

A third limitation is that in Chapter 4 I only included girls, whereas in my other chapters I included both sexes. This points to an important consideration, that age is only a proxy for developmental stage. A wide body of research shows that puberty has a significant effect on cognitive and social development as well as mental health symptoms. Furthermore, puberty onset differs appreciably between the sexes and within the sexes across individuals. Therefore, age is not a very accurate indicator of developmental stage, especially when both sexes are included.

I made a conscious effort to diversify my participant pool and tried to collect data from individuals from a range of socioeconomic backgrounds and ethnicities. However, a fourth limitation is that my samples are still not representative, and this limits the generalisability of the results. For example, my first three studies include adolescents from London schools only. There are known effects of urbanicity on cognitive development, so the effects reported here should be tested in rural samples. My final study had the least representative samples, because of the specificity of the groups studied. There were many unique features of these samples, some of which I discussed in Chapter 6. For example, all of the university students attended NYU, which is an expensive private university in one of the most expensive cities in the US. Almost all of the high school children were attending highly selective and competitive public high schools in New York City. Therefore, my results would need to be replicated in more representative samples and consequently should be interpreted with caution.

A fifth limitation is that for Chapters 3–5, I tested participants in groups in the classroom. I controlled for the number of children present in the classroom, but there may be other unmeasured confounding factors that affected participants' performance. Indeed, there is a large literature on the effect of observers on adolescent behaviour, especially peer observers.

When there is a monetary bonus (Chapter 5), participants may compare their winnings and compete to gain more than their friends. Therefore, with greater resources, it would be more rigorous to test adolescents alone.

In Chapters 3 and 6, I used virtual players to deliver social cues to participants. Specifically, Chapter 3 involved the utilization of a virtual agent to offer advice to participants, while Chapter 6 incorporated virtual players who prescribed the social norm. This raises a sixth limitation that participants may not have treated these games in the same way as if human players had been involved. I made a deliberate choice not to use deception to convince participants that the other players were genuine individuals in these studies. This decision was made to mitigate confounding individual differences in the perceived plausibility that other players were real people. Employing deception could complicate the interpretation of age-related differences in task performance because of age-related variations in the perceived plausibility of the instructions given to participants. Nonetheless, it could be argued that the cognitive processes engaged by participants to discern advice from the virtual advisor or to learn the social norm from the virtual players would be different if the players were human counterparts. This could also introduce interesting avenues for future research, by comparing behaviour when the other players have different relations with the participants (e.g. friends versus parents) or belong to different demographic groups (e.g. in-group versus out-group).

Throughout my thesis I used total scores on individual questionnaires to assess mental health symptoms. However, it is well understood that mental health symptoms often share common symptoms and that individuals often meet the criteria for multiple diagnoses, and this comorbidity between diagnoses is especially high in depression and anxiety. There is growing consensus in the mental health neuroscience field that diagnostic labels, such as “depression”, are unlikely to capture the complex nature of mental health conditions. Specifically, it is unlikely that diagnostic categories reflect unitary mechanistic constructs or that they are informative for identifying risk factors or can be targeted by single interventions. Over the past decade this realisation has led to increasing adoption of a transdiagnostic approach, whereby researchers investigate symptom dimensions (e.g. using factor analysis as in Rouault et al., 2018) or individual symptoms (e.g. focussing assessment on anhedonia, a core symptom of depression but also a transdiagnostic risk factor, as in Auerbach et al. 2017) or networks of symptoms (Fried et al., 2017), with the aim of uncovering mechanisms of mental health that may be more informative for mechanistic understanding and treatment development (Wise et al., 2023).

Utilising a transdiagnostic approach in this thesis was not easily achievable for a number of reasons. Firstly, item-level factor analysis requires larger sample sizes than recruited here in order to produce robust results. Second, the transdiagnostic approach requires collection of a large range of symptoms (e.g. nine questionnaires collected in Rouault et al., 2018), requiring lengthy testing sessions, which are impractical for adolescents especially in school settings (where sessions often take place on lunch break, during a class or after school).

Finally, the power analyses conducted in this thesis were conducted based on effect sizes for detecting age-related changes in cognition. However, in many of the chapters I also conducted supplementary analyses, including investigating mental health and other cognitions via questionnaire. The magnitude of these associations may be smaller than age-related changes and thus require a larger sample size to detect them. This means that many of the chapters may have been underpowered to detect associations with mental health symptoms. I was especially limited in power for between-subjects analyses in Chapter 6, due to the time constraints on recruiting participants to enter the study within a strict two-week window.

Implications and recommendations for future research

The studies in this thesis make a first step towards understanding the cognitive mechanisms underlying self-concept development and autonomy in adolescence. In this section, I will discuss the implications of this work for developmental science, and also the ways in which we could build upon this research to allow us to draw greater implications for social policy and mental health interventions.

In Chapter 3, I showed that the ability to reflect on decisions and sensibly incorporate advice matures over adolescence. I extended previous work, using recent methodological and analytic developments to measure metacognitive abilities independent from cognitive performance. The results imply that early adolescence is a key developmental period for metacognitive and advice-taking capacities. Therefore, early adolescence may be a critical period for educational interventions to enhance maturation of these skills.

Dual systems theory traditionally centres on the extenuated development of cognitive control capacities during adolescence, which are purportedly supported by maturation of prefrontal brain regions (Shulman et al., 2016). Nevertheless, a substantial body of evidence suggests that metacognitive capacities are associated with activation in a comparable network of regions, including the rostral and dorsal aspect of the lateral prefrontal cortex (Fleming & Dolan, 2012). This prompts consideration for expanding the dual systems model to encompass not only cognitive control processes but also other reflective processes facilitated by the prefrontal cortex. Here, I presented evidence indicating more accelerated development of such processes in early compared to later adolescence. Therefore, it is plausible that the developmental trajectories of prefrontal-related cognitive capacities may not follow a simple linear trajectory, warranting a more nuanced exploration of non-linear developmental trajectories and the intricate interplay between the development of cognitive control and metacognition. Inclusion of an adult sample or longitudinal samples in future studies would enable us to further delineate the developmental trajectory of metacognition. This would elucidate whether the observed performance in the older groups (12–13- and 16–17-year-olds) is comparable to adults' performance, or if there exists an additional phase of development later in adolescence or early adulthood.

It would be interesting to build on this work to investigate how metacognitive judgements about individual decisions are built upon to create a sense of self-efficacy more generally. Recent work has started to investigate how local metacognitive judgements (e.g. confidence judgements about individual decisions) are associated with global metacognitive judgements (e.g. predictions about performance over an entire block or task) and how these are built into self-beliefs (e.g. about general self-efficacy). There is a large body of work on how self-efficacy (measured using questionnaires) affects not only sense of self and wellbeing but also the set of choices individuals believe is available to them (Bandura, 1982; Zimmerman, 2000). Taking a developmental perspective could increase our understanding of how these beliefs are formed, for example, whether the ability to make local judgements develops initially, how these judgements are built upon to make more global judgements or whether more global beliefs develop first and are used to restrain local judgements of performance. An important topic for future work would be to assess the associations between different levels of generalisation at different ages, to understand whether the ability to build upon local judgements or to reflect on more global judgements in order to make local judgements matures over adolescence.

This work extends existing theoretical accounts of adolescent decision-making, particularly those emphasizing the importance of peer influence during this developmental period (S.-J. Blakemore, 2008; Tomova et al., 2021). Introducing a manipulation of the advisor relationship with the participant (e.g. peer versus parent) could further illuminate the extent to which advice-taking is dependent on advisor relations. Nevertheless, the current findings indicate that, in the context of a neutral advisor, young adolescents exhibit a discerning ability to sensibly incorporate advice into their decisions. This complements prior work that shows that adolescents do not necessarily blindly follow peer advice, but are more likely to follow advice when they are particularly uncertain (Reiter et al., 2019)s.

In this way, the dynamics of social influence may be more nuanced than originally proposed. Some researchers posit that peer influence exerts a more substantial impact when adolescents are making normative judgements, as opposed to informational judgements (Lourenc et al., 2015). Notably, in Chapter 3, in which informational rather than normative judgements were required, young adolescents exhibited comparable performance to their older counterparts in sensibly incorporating advice. This suggests a nuanced and context-dependent nature of adolescent decision-making. Adolescents demonstrate a capacity to critically evaluate evidence presented by others against their own decisions. Yet, their considerations may prioritise factors such as approval or social status over rigid adherence to their own beliefs (Do et al., 2020).

The work presented in this thesis, in conjunction with prior research, contributes to our evolving understanding of how adolescents navigate (social) decision-making. It suggests that adolescents possess the cognitive capacity to weigh external advice against their own judgements. Therefore, it may be the case that adolescent peer influence is instead explained by the incorporation of social motivations (e.g. approval) into their decisions. Future work could further investigate the hypothesis that such behavioural flexibility during adolescence promotes better social relationships (Becht et al., 2021a).

It could also be fruitful to expand upon my investigation of advice-taking capacity in young people. For example, if the development of metacognitive ability influences the ability to incorporate advice sensibly, perhaps more generalised self-beliefs will influence more complex decision making, e.g. when and from whom do young people take advice about educational choices (what subjects to pick, whether and where to go to university), career choices or voting choices. This could also be important in mental health research, where young people are given increasing capacity over treatment plans as they mature. Therefore, further understanding how young people's beliefs about themselves influence their capacity for advice taking could have many wide-reaching implications for mental health and social policy.

Preliminary evidence suggests the potential predictive value of self-referential memory biases in relation to longitudinal depressive symptoms among children aged 6–9 years (Goldstein et al., 2015). I observed a peak in negative self-judgements around the same age that depression onset is most common. Consequently, it would be interesting to explore the associations between age-related changes in self-judgement, self-referential memory biases and the trajectory of depressive symptoms. To further deepen our understanding, it would be interesting to investigate whether differences in self-judgements and self-referential memory biases serve as risk factors for the emergence of depression or whether they manifest as a consequence of symptoms. This would require longitudinal analyses during adolescence, measuring both self-referential memory biases and depressive symptoms over time. This would provide greater insight into the interplay between self-perception, memory processes and depressive symptomatology, shedding light on potential causal mechanisms and potential targeted interventions for at-risk populations.

The findings from Chapter 5 provided novel evidence that adolescents' capacity to use choice to learn about themselves shows an age-related increase. This observation could hold implications for social policy, particularly considering the transitional phase of adolescence characterised by the concurrent struggle for independence and the persistent obligations associated with education (e.g. legal obligations to attend school) and family (e.g. living at home and thus abiding by parents' rules). This study implies that as adolescents mature, their capacity to learn about themselves through autonomous decision making is enhanced. It would be particularly interesting to directly test this within the framework of Spreading of Alternatives, by comparing conditions in which adolescents are able to make decisions for themselves and conditions where others make decisions for them, such as their parents. I would predict that adolescents would only update their own preferences when afforded the opportunity to make decisions independently.

In conjunction with the results observed in Chapter 6, where older adolescents demonstrated a stronger association between autonomy and both positive and negative affect and a stronger negative association between autonomy and negative affect compared with younger adolescents, these findings suggest that feelings of autonomy may play a crucial role in adolescent self-concept development and overall wellbeing. Therefore, as adolescents age, it may be important to provide increasing opportunities to exercise decision-making agency. Further research could examine the impact of providing advice to caregivers, on when and how to gradually relinquish control over their children's daily choices. This could also compliment the future work I propose above, investigating adolescents' ability to incorporate advice into their decisions. With greater understanding of adolescent advice-taking, learning from independent decisions and enjoyment from feelings of autonomy, we can better scaffold social policy to support adolescents to smoothly transition into independence. To build on this, it would be interesting to investigate whether the association between feelings of autonomy and affect would be moderated by adolescents' ability to refine preferences through choice on the value refinement task.

In Chapter 5, I did not find evidence that depressive symptoms were associated with lower ability to use choice to refine preference estimates. Instead depressive symptoms were associated with greater refinement of preferences through choice, but this was not reflected in certainty and confidence judgements. This provides tentative evidence that the reported difficulty in decision making during depressive episodes could be a due to a disruption of metacognitive processes, rather than in decision making itself. However, there were disparities in the results between continuous measures of depressive symptoms and categorical classifications (based on a questionnaire cut-off). Therefore, it would be important to replicate this effect in a larger sample before drawing implications for mental health care.

In my final experimental chapter, I demonstrated that exploratory behaviours during adolescence were associated with positive outcomes in momentary affect and social network development. While the dual systems model tends to interpret adolescent exploratory behaviours as indicative of a failure in cognitive control, recent work challenges this proposal. Critics argue that the dual systems model inadequately explains instances where exploratory (risk-taking) behaviour is strategic and involves heightened cognitive control (Do et al., 2020). For instance, trying a new drug for the first time may require adolescents to exert greater cognitive control to override the habitual response of risk avoidance in order to engage in behaviour valued by a peer group. Drawing parallels with animal research, which demonstrates elevated exploratory behaviours in the equivalent developmental period to adolescence in multiple non-human primates and rodents (Macrì et al., 2002; Parker et al., 2007), suggests that exploration may be an adaptive feature of this developmental stage. Synthesizing the findings of Chapter 5 and 6 together, I begin to build a potential explanation of how exploration can be beneficial. By sampling their expanding decision spaces, adolescents may be able to learn about the self, the social environment and the world, and this behaviour could be reinforced through increased affect. With further comparative research, we could investigate the adaptive and strategic nature of these exploratory behaviours, challenging the notion that they are merely a by-product of an immature brain.

Utilising insights from comparative neuroscience offers valuable perspectives on the potential adaptive nature of typical adolescent behaviours, as exemplified by naturally occurring exploratory behaviours in non-human animals' adolescence. Additionally, it aids in understanding human adolescence by allowing us to assess the biological plausibility of existing models. While many cognitive processes investigated in this thesis rely on subjective reports of experience, some behaviours presumed to depend on such reports have been observed in non-human animals through well-designed paradigms.

For example, there is consensus that animals exhibit uncertainty monitoring processes that are resembling human metacognition, deciding to increase information search in contexts where less certain about the correct response (although some have suggested this could rather be due to simple associative-learning; Kepecs & Mainen, 2012; Smith, 2009). There is also evidence suggesting that choice-induced preference change is observable in capuchin monkeys (Egan et al., 2007), though it is crucial to note that the statistical artefact explanation, as discussed in

Chapter 5, is not accounted for here. Limited research has examined the development of metacognition and choice-induced preference change in animals, making specific comparisons to adolescence less straightforward. Nonetheless, if animals exhibit these behaviours, and assuming that animals lack complex, multi-dimensional self-concepts, it raises intriguing questions about whether similar behaviours in human adolescence are dependent on a sophisticated, integrative self-system, as some have suggested (Harter, 2012; Sebastian et al., 2008b; Sui & Humphreys, 2015a). In essence, this prompts an inquiry into whether the behaviours observed in this thesis are unique to human adolescence, contributing to the construction of a complex underlying self-concept, or whether they represent the development of something less intricate: simple behavioural responses to changing environments.

Finally, it would be interesting to further investigate how mental health symptoms change adolescents' ability to learn from and gain positive affect through exploration. I found that anxiety disrupted the association between exploration and positive affect during the first three months of a new school or university. Future work could investigate this effect in more depth, to understand the reasons why this link would be weaker when individuals are more anxious. In general, further exploring the risk factors and impact of developing mental health symptoms during the transition to a new school is an important avenue for future work, as it could provide insight into how caregivers, schools and universities can provide the right advice and support for young people during this period of major change.

Concluding remarks

This thesis has investigated multiple processes underlying self-concept development during adolescence, highlighting the cognitive strategies that adolescents employ to reflect on, store, refine and explore self-referential information. By focusing on these strategies, my studies have provided important insights into how they facilitate adolescents' path toward independence, and how they relate to symptoms of mental health conditions. Many directions for future research have been suggested, which when built on have potential to inform interventions and strategies aimed at supporting adolescents in constructing a positive self-concept and promoting mental health.

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